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(54) Title: HIGH AFFINITY LIGAND FOR p75 NEUROTROPHIN RECEPTOR

(57) Abstract: The present invention provides an isolated protein comprising a pro-domain of a proneurotrophin, methods for producing the protein, and pharmaceutical compositions containing the isolated protein. The invention also provides a nucleic acid molecule which encodes the protein and a vector containing the nucleic acid molecule. The present invention further provides a method for cleaving a proneurotrophin protein to a mature neurotrophin. In addition, the invention relates to methods for inducing apoptosis in a cell of a mammal expressing p75 surface receptors or p75 and trk receptors. The methods include causing the p75 receptor to bind a pharmaceutical composition containing a pro-domain of a proneurotrophin or administering to the mammal an effective amount of a cleavage-resistant proneurotrophin and an inhibitor of trk activation. The invention also relates to a method for inhibiting apoptosis of a cell in a mammal by administering an effective amount of a molecule which inhibits binding of a proneurotrophin to a p75 receptor. Also provided, are kits and methods for screening a human for a condition associated with undesired apoptosis.

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HIGH AFFINITY LIGAND FOR p75 NEUROTROPHIN RECEPTOR

This application asserts the priority of U.S. provisional application serial number 60/293,823 filed May 25, 2001 and U.S. provisional application serial number 60/305,510 filed July 13, 2001, the specifications of which are incorporated by reference in their entirety.

The invention described in this application was made with funds from the National Institutes of Health, Grant Number R01 NS 30687. The United States government has certain rights in the invention.

BACKGROUND OF THE INVENTION

The neurotrophins, including nerve growth factor (NGF), brain derived neurotrophic factor (BDNF), neurotrophin 3 (NT-3), and neurotrophin 4/5 (NT-4/5), are among the molecular determinants that regulate the generation of diverse neuronal populations and the maintenance of their functions within the nervous system (Lewin GR, et al. 1996. *Ann. Rev. Neurosci.* 19:289; Theonen H. 1995. *Science* 70:593). The binding of mature neurotrophins to their cognate receptor tyrosine kinase, trks, (i.e., NGF to trk A, BDNF and NT-4/5 to trk B, and NT-3 to trk C) triggers a cascade of anti-apoptotic events that ensure neuronal survival. In competition analysis, the mature form of NGF is more potent than the larger pro-forms of NGF in trk A binding (Chen YE, et al. 1997. *Mol. Cell Endocrinol.* 127:129) and in promoting cell survival.

In addition to trks, all mature neurotrophins are thought to interact with the p75 receptor. The p75 receptor belongs to the tumor necrosis factor (TNF) receptor superfamily. The extracellular domain of p75 that is the most critical for neurotrophin binding is reported to be the third and fourth cysteine loops (Choi DW. 1990. *J. Neurosci.* 10:2493; Yan H, et al. 1991. *J. Biol. Chem.* 266:12099).

The mechanism of signaling elicited by activated trks is unequivocal. However, the molecular and biological consequences of mature neurotrophin-p75 interaction have been confounding.

For example, structural analysis indicates that multiple regions of the extracellular domain of the p75 receptor contribute to mature NGF binding. Point mutagenesis suggests that the variable loops of mature neurotrophins are most important for interaction with p75 (Ryden M, et al. 1995. *Embo J.* 14:1979). Despite their importance for binding, these variable loops exhibit the highest degree of variation between the different mature neurotrophins. Nevertheless, all mature neurotrophins bind to p75.

Similarly, kinetic analysis of mature NGF-p75 binding demonstrates that mature NGF binds very rapidly, and dissociates very rapidly (Mahadeo DL, et al. 1994. *J. Biol. Chem.* 269:6884; Tait JF, et al. 1981. *J. Biol. Chem.* 256:11086). These results are perplexing, since most ligand-receptor interactions exhibit slow dissociation rates. In contrast, mature NGF binds to trk A slowly and is released very slowly.

When both types of receptors are present in the same cell, p75 is reported to enhance the affinity of trk A towards mature NGF (Mahadeo DL, et al., 1994. *J. Biol. Chem.* 269:6884; Hempstead, B.L., et al. 1991. *Nature* 350:678-683). In the absence of trk, however, binding of mature neurotrophin to p75 is reported to induce apoptosis (Chao MV, et al., 2001. *Curr. Opin. Neurobiol.* 11:281-286.). In addition, apoptosis is believed to be induced in neuronal cells via p75 when mismatching of mature neurotrophin-trk pairing occurs (Majdan M. 1999. *Int J. Dev. Neurosci.* 17:153).

For example, superior cervical ganglionic neurons express trk A and p75, but not trk B. As mentioned above, it is known that mature BDNF binds to trk B and to p75, but not to trk A. As a result of the mismatching of mature neurotrophin-trk pairing, treatment of superior cervical ganglionic neurons with mature BDNF triggers p75-mediated apoptosis (Bamji SX, et al. 1998. *J. Cell. Biol.* 140:911). Therefore,

apoptosis is believed to be induced in neuronal cells when p75 is expressed alone. In addition, when both p75 and trk are present in the same cells, apoptosis is induced during mismatching of mature neurotrophin-trk pairing or when trk mediated signaling is inhibited.

Accordingly, currently available data have refined the original neurotrophin hypothesis. The original hypothesis stated that the lack of trophic support leads to selective neuronal loss (Korsching S. 1993. *J. Neurosci.* 13:2739). The refined model states that inappropriate activation of p75 by mature neurotrophins will lead to apoptosis.

If the refined model proves to be correct, the clinical implications are very significant. The p75 receptor is up-regulated in neuronal populations after nervous system stress or injury (Roux PP, et al., 1999. *J. Neurosci.* 19:6887; Widenfalk J, et al. 2001. *J. Neurosci.* 21:3457; van Eden CG, et al. 1994. *Brain Res. Dev. Brain Res.* 82:167) and in glia cells of multiple sclerosis patients (Dowling P, et al. 1999. *Neurology* 53:1676; Chang A, et al. 2000. *J. Neurosci.* 20:6404). Therefore, under the refined model, activation of p75 by mature neurotrophins in these cells will lead to apoptosis.

Recent findings have implicated apoptosis as a common endpoint of various nervous system injuries and environmental insults. Dying neurons in selected instances of, for example, hypoxic ischemia (Choi DW. 1990. *J. Neurosci.* 10:2493), viral infection (Lin KI, et al. 1996. *J. Cell Biol.* 131:1149), and neurodegenerative disorders (Roy N, et al. 1995. *Cell* 80:167; Liston P, et al. 1996. *Nature* 379:349) display a number of hallmark characteristics of apoptotic cells.

There is increasing evidence that mature neurotrophins and their receptors (p75 and trks) can also modulate a variety of cellular events in non-neuronal tissues (Lomen-Hoerth C, et al. 1995. *J. Neurochem.* 64:1780). In some instances, p75 expression is distinct from that of the trks (Wheeler EF, et al. 1998. *J. Comp Neurol.*

4:407). The distinct expression supports a trk-independent mechanism for p75 function in non-neuronal cells.

For example, NGF and p75 immunoreactivities have been detected in developing incisors (Mitsiadis TA, et al. 1993. *Differentiation* 54:161). In human adults, upregulation of p75 in renal biopsies is correlated with various glomerulopathies. The increased expression of p75 detected in renal biopsies apparently recapitulates a normal developing state during kidney development. Both p75 and NGF have been detected in developing muscles. In vitro analysis of the muscle cell line C2C12 suggests that p75-mediated myogenic differentiation is inhibited by NGF. The inhibition of myogenic differentiation by the NGF-p75 interaction occurs in a trk-independent manner. The expression of p75 is also detected in the atherosclerotic plaques of smooth muscle cells, as well as in many carcinoma cell types.

In addition, the expression of p75 has been observed in hair follicles (Yardley G, et al. 2000. *Exp. Dermatol.* 9:283; Botchkarev VA, et al. 2000. *FASEB J.* 14:1931). Both p75 and trks are found in hair follicles in the anagen (active growth) phase of hair growth (Botchkarev VA, et al. 2000. *FESEB J.* 14:1931). However, during the catagen (regression) phase, there is a disappearance of trk A, trk B, and trk C. The expression of p75 alone is markedly upregulated and detected in cells undergoing apoptosis (Botchkarev VA, et al. 2000. *FESEB J.* 14:1931). These findings suggest that p75 is involved in both the survival and apoptosis of cells in the hair follicle.

The interaction of p75 and neurotrophins in both neuronal and non-neuronal cells play a very important role in normal tissue development, as well as in many disease states. Currently available data suggest that p75 promotes both cell survival and apoptosis. However, conflicting and perplexing data in the prior art, such as the data described above, would have precluded the consideration of modulating mature neurotrophin-p75 interaction as a practical means for treating particular disorders.

Unwanted cell growth is a problem in various hyperproliferative conditions, such as cancer, acne, shingles, etc. Unwanted cell death is a problem in other conditions, such as injuries due to trauma, hair loss, etc. Thus, there is an immediate need for modulating apoptosis.

In certain instances, it is desirable to promote the p75-mediated apoptosis of deleterious cells. In other instances, it is desirable to inhibit the p75-mediated apoptosis (for example, in dying neurons and in dying hair follicles) without affecting the survival promoting functions of mature neurotrophins.

SUMMARY OF THE INVENTION

In one embodiment, the invention relates to an isolated protein comprising a pro-domain of a proneurotrophin, the pro-domain comprising a pro-domain conserved region, the conserved region being an amino acid sequence having at least approximately 85% identity to amino acid residues approximately at positions 79-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3, or 43-57 of human NT-4/5.

In another embodiment, the invention relates to a pharmaceutical composition that comprises a protein and a pharmaceutically acceptable additive, the protein comprising: a pro-domain of a proneurotrophin, the pro-domain comprising a pro-domain conserved region, the conserved region being an amino acid sequence having at least approximately 85% identity to amino acid residues approximately at positions 84-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3, or 43-57 of human NT-4/5.

In another embodiment, the invention relates to an isolated protein comprising: (i) a pro-domain of a proneurotrophin, the pro-domain comprising a pro-domain conserved region; (ii) a mature neurotrophin domain; and (iii) a connector that joins the pro-domain conserved region to the mature neurotrophin domain and that is resistant to protease cleavage.

In another embodiment, the invention relates to a pharmaceutical composition that comprises a protein and a pharmaceutically acceptable additive, the protein comprising: (i) a pro-domain conserved region; (ii) a mature neurotrophin domain; and (iii) a connector that joins the pro-domain conserved region to the mature neurotrophin domain and that is resistant to protease cleavage.

In another embodiment, the invention relates to a nucleic acid molecule that encodes a protein described above.

In another embodiment, the invention relates to a method for producing a protein described above, the method comprising expressing a nucleic acid molecule that encodes the protein in a host cell.

In another embodiment, the invention relates to a vector comprising a nucleic acid molecule described above.

In another embodiment, the invention relates to a host cell comprising a nucleic acid molecule described above.

In another embodiment, the invention relates to a method for inducing apoptosis in a cell that comprises p75 receptors on its surface, the method comprising causing the p75 receptor to bind a pharmaceutical composition described above.

In another embodiment, the invention relates to a method for cleaving a proneurotrophin protein to a mature neurotrophin, the method comprising contacting the proneurotrophin protein with MMP 3, MMP 7, or plasmin.

In another embodiment, the invention relates to a method for inhibiting the cleavage of a proneurotrophin to a mature neurotrophin in a mammal in need thereof, the method comprising administering to the mammal an inhibitor of a protease that cleaves the major cleavage site found in native proneurotrophin proteins.

In another embodiment, the invention relates to a method for preventing or treating atherosclerosis in a mammal, the method comprising administering to the mammal an inhibitor of a protease that cleaves the major cleavage site found in native proneurotrophin proteins.

In another embodiment, the invention relates to a method for inducing cell apoptosis in a mammal in need thereof, wherein the cell is susceptible to apoptosis initiated by the binding of a proneurotrophin to a p75 receptor, the method comprising treating the mammal with an inhibitor of a protease that cleaves the major cleavage site found in native proneurotrophin proteins.

In another embodiment, the invention relates to a method for inducing apoptosis of cells expressing p75 receptors and trk receptors in a mammal in need thereof, the method comprising administering to the mammal an effective amount of a cleavage-resistant proneurotrophin and an inhibitor of trk activation.

In another embodiment, the invention relates to a method for inhibiting apoptosis of a cell in a mammal in need thereof, the method comprising administering to the mammal an effective amount of a molecule that inhibits the binding of a proneurotrophin to a p75 receptor.

In another embodiment, the invention relates to a method to screen a human patient for a condition associated with undesired apoptosis, the method comprising determining whether the level of at least one proneurotrophin, or of a conjugate between a p75 receptor and at least one proneurotrophin, in a biological sample of the patient is elevated (i.e. higher than normally occurs in the absence of the condition), wherein elevated levels of proneurotrophins or p75/proneurotrophin conjugates indicate the existence of the condition.

In another embodiment, the invention relates to a method for inhibiting apoptosis-mediated hair follicle regression in a mammal in need thereof, the method

comprising administering to the mammal an effective amount of a molecule that inhibits the binding of a proneurotrophin to a p75 receptor.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1A: Primary Protein Sequence from Human NGF (GenBank Accession Number: AAA59931);

Figure 1B: Schematic Representation of Monomeric, Unglycosylated Human NGF Isoforms According to Prior Art;

Figure 1C: Schematic Representation of Modified Human Pro-NGF According to Invention;

Figure 2A: Primary Protein Sequence from Human BDNF (GenBank Accession Number: AAA69805);

Figure 2B: Schematic Representation of Monomeric, Unglycosylated Human BDNF Isoforms According to Prior Art;

Figure 2C: Schematic Representation of Modified Human Pro-BDNF According to Invention;

Figure 3A: Primary Protein Sequence from Human NT-3 (GenBank Accession Number: AAA59953);

Figure 3B: Schematic Representation of Monomeric, Unglycosylated Human NT-3 Isoforms According to Prior Art;

Figure 3C: Schematic Representation of Modified Human Pro-NT-3 According to Invention.

Figure 4A: Primary Protein Sequence from Human NT-4/5 (GenBank Accession Numbers: AAA60154 & AAA20549)

Figure 4B: Schematic Representation of Monomeric, Unglycosylated Human NT-4/5 Isoforms According to Prior Art.

Figure 4C: Schematic Representation of Modified Human Pro-NT-4/5 According to Invention.

Figure 4D shows the Human p75 Receptor Sequence (Accession Number: g69056)

Figure 5A: Alignment results for the human proneurotrophins. The amino acid sequences of human NGF, BDNF, NT-3 and NT-4/5 are aligned for best fit. The signal sequences are boxed (shown as the N-terminal 19-24 amino acids). Conserved positions are shown: * indicates an amino acid conserved in all neurotrophins; single and double dots show positions with partial conservation. The mature sequences are the longer boxed sequences.

Figure 5B: Sequence Comparison for NGF across Species.

Figure 5C: Sequence Comparison for BDNF across Species.

Figure 5D: Sequence Comparison for NT-3 across Species.

Figure 5E: Sequence Comparison for NT-4/5 across Species.

Figure 6: Purification of His-tagged native (cleaved) NGF, and a His-tagged point mutant (proform) NGF. Media from 293 cells stably expressing constructs of native or mutant NGF incorporating a His tag at the carboxy-terminus, or the vector alone were purified using Ni-column chromatography. Proteins eluted with imidazole

were subjected to SDS-PAGE and Western blotted with anti-His antisera. Mature (M), and cleavage resistant proform (Pro) are indicated.

Figure 7. Purified pro-NGF (0.8 $\mu\text{g/ml}$) was incubated with the indicated proteinases with or without inhibitors and proteolytic products detected by Western blot analysis with anti-NGF antibody.

Figure 8: Binding analysis of mature and cleavage-resistant pro-NGF to TrkA or p75^{NTR} receptors. Cleavage resistant pro-NGF or commercial mature NGF were assayed for their ability to displace ¹²⁵I-radiolabeled commercial mature NGF (1nM) from 293 cells expressing TrkA (A) or A875 cells expressing p75^{NTR} (B). Competition analysis of equilibrium binding was performed using a whole-cell assay. Cells were incubated with 1 nM radioiodinated NGF in the presence or absence of unlabeled mature NGF or unlabeled proNGF from 0.005 to 7 nM concentration for 1 hour at 0.4°C. Nonspecific binding measured in parallel incubation with 500-fold excess mature NGF was less than 10% of total binding; all results were corrected for this non-specific binding. Each point represents the mean \pm standard deviation of quadruplicate determinations. Squares, commercial mature NGF; open circles, cleavage resistant pro-NGF. Competition with purified mature NGF yielded results that were comparable to those obtained with commercial NGF.

Figure 9: Distinct biological activities are elicited by cleaved and uncleaved NGF. (A) Induction of apoptosis by NGF and pro-NGF using p75 expressing smooth muscle cells. Cells expressing p75 (p75Ts-Tag-SMC) were cultured at 39.5°C for 96h to permit differentiation, then incubated with the indicated concentration of commercial NGF (open circles), His-tagged NGF (filled circles), His-tagged pro-NGF (filled squares), or column eluates from vector transfected cells (open squares). After 18h, cells were subjected to TUNEL analysis and were stained with DAPI to visualize nuclei. At least 400 cells/condition were counted, and the result is representative of two independent experiments with different preparations of NGFs. (B) Effects of mature NGF and pro-NGF on PC12 cell neuritogenesis. trk A-overexpressing PC12 cells were treated with His-tagged cleaved NGF, His-tagged uncleaved NGF,

commercial NGF or column eluates from vector-transfected controls for 48h in serum free media. Cells were scored for neurite processes greater than one cell body in length. (C and D) Effects of mature NGF (C) and pro-NGF (D) on superior cervical ganglia neurons. Superior cervical neurons were treated with 0.4 nM of mature or pro-NGF for 36 h and fixed. Cells were double-labeled for Trk immunoreactivity and TUNEL positivity with DAPI staining for the nuclei. The percentage of neurite expressing cells (white typeface) and apoptotic cells (green typeface) is indicated. Cells treated with diluent alone yielded $30 \pm 10\%$ apoptosis. Scale bar, 30 μ m. At least 200 cells per condition were scored, and results are representative of three independent experiments using different preparations of NGFs.

Figure 10: Proteolytic cleavage of BDNF from Ad-infected (A) 293T or (B) murine endothelial cells by plasmin and MMPs in the supernatants of Ad-infected cells. Inhibition of cleavage by plasmin using the inhibitor aprotinin or peptide inhibitor of MMPs. (C) BDNF expressing endothelial cells were incubated with plasmin or plasmin plus aprotinin. Unpro=unprocessed form; Pro=processed form.

Figure 11. Tissue expression of neurotrophins. Western blot analysis of adult mouse tissue (50 g) subjected to reduction with dithiothreitol and alkylation with iodoacetamide to inhibit neurotrophin dimerization, were probed with antiserum specific for epitopes in the mature forms of NGF (A) or BDNF (B).

Figure 12. Western blot analysis of pro-NGF and pro-BDNF specific antibodies. Recombinant human mature BDNF, or mature mouse NGF, and recombinant cleavage resistant mouse pro-BDNF or recombinant mouse pro-NGF were separated by SDS-polyacrylamide gel electrophoresis. Pro-BDNF was generated by infecting 293 cells with a recombinant adenovirus encoding murine BDNF which had been mutated at positions 434-439. Blots were probed with the indicated antisera to NGF (A) or BDNF (B). Apparent molecular masses are indicated.

Figure 13. Western blot analysis of human carotid atherectomy specimens to detect neurotrophin isoforms: (A) Mature BDNF, (B) Pro-BDNF, (C) Mature NGF, and (D) Pro-NGF. Atherectomy specimens in toto (A), or those subjected to microdissection of the media (M), fibrous cap (FC), necrotic core (NC) were solubilized in detergent, and 70 µg aliquots of total protein separated by SDS PAGE, along with recombinant BDNF (rBDNF), murine adult heart extracts (Heart), purified cleavage resistant proNGF (proNGF) or murine mature NGF (NGF). The schematic diagram of the medial, fibrous plaque and necrotic core regions are indicated (E).

DETAILED DESCRIPTION OF THE INVENTION

The present invention is based on the surprising discovery by the inventors that uncleaved proneurotrophins bind with higher affinity to p75 than do the cleaved, mature neurotrophins. Moreover, the inventors have discovered that uncleaved proneurotrophins are more effective than mature neurotrophins in inducing apoptosis of cells that express p75, especially cells that express large numbers of p75, or that express p75 exclusively, relative to trk receptors.

In this specification, the p75 receptor is the member of the TNF receptor superfamily that binds all neurotrophins. The p75 receptor has sometimes been called the low affinity neurotrophin receptor.

While the present invention is not limited by any particular mechanism or theory, these results, taken together, resolve the question of biological activity of the proneurotrophins. The inventors have discovered that proneurotrophins induce apoptosis of cells via interaction of the proneurotrophins with the p75 receptor. Therefore, it is now, for the first time, apparent that regulated cleavage of proneurotrophins alters their biological activity from promoting death of neuronal cells to promoting survival, and that the proneurotrophins are an integral part of the system.

Proteins:

As will be discussed in more detail below, one embodiment of the present invention relates to cleavage resistant proteins comprising modifications of native proneurotrophins. Cleavage of such native proneurotrophins generate the family of mature neurotrophins. Proteins comprising modifications of native proneurotrophins in accordance with the invention will be referred to herein as modified or cleavage-resistant proneurotrophins.

The native, mature neurotrophin family is well defined, and the members share a number of physical and biological characteristics. For example, biologically active mature neurotrophins are all cleaved from a precursor proneurotrophin at a consensus cleavage site of the furin type (R-X-R/K-R). This cleavage site will be referred to as the major proneurotrophin cleavage site (or, simply, the major cleavage site). As can be seen from Figures 1A-4A, the major human proneurotrophin cleavage site includes R-S-K-R in NGF, R-V-R-R in BDNF, R-R-K-R in NT-3, and RSRR in NT-4/5.

The mature members of the family interact with the p75 receptor and with the family of trk receptors. All of the mature neurotrophins are involved in the development, survival, and function of neurons in both the peripheral and central nervous systems. The molecular masses of monomeric, unglycosylated mature neurotrophins range from approximately 13.4 to approximately 14 kDa. The isoelectric points of the mature neurotrophins range from approximately 9 to approximately 10.

Structurally, six cysteine residues conserved in the mature neurotrophins give rise to three intra-chain disulfide bonds. The neurotrophins exist in solution as non-covalently associated dimers.

Members of the mature family of neurotrophins include nerve growth factor, (NGF), brain derived neurotrophic factor (BDNF), neurotrophin 3 (NT-3), and

neurotrophin 4/5 (NT-4/5 or NT-4). The molecular masses of monomeric, unglycosylated mature NGF, BDNF, NT-3, and NT-4/5 are approximately 13.5, 13.5, 13.6, and 13.9 kDa, respectively.

The precursors of the mature neurotrophins, i.e. the native proneurotrophins, are also members of a well defined family. For example, the molecular masses of monomeric, unglycosylated proneurotrophins, including the N-terminal signal sequence, range from approximately 22 to approximately 30 kDa. The isoelectric points of the proneurotrophins range from approximately 8 to approximately 9. Most characteristically, the proneurotrophins are cleaved by proteases at or near the major proneurotrophin cleavage site to produce a mature neurotrophin.

Members of the proneurotrophins include pro-NGF, pro-BDNF, pro-NT-3, and pro-NT-4/5. The molecular masses of monomeric, unglycosylated pro-NGF, pro-BDNF, pro-NT-3, and pro-NT-4/5 are approximately 27.0, 27.8, 29.4, and 22.4 kDa, respectively. The GenBank accession numbers of human pro-NGF, pro-BDNF, pro-NT-3, and pro-NT-4/5 are AAA59931, AAA69805, AAA59953, and AAA60154/AAA20549, respectively. These sequences are incorporated herein by reference, and are displayed in Figures 1A-4A.

In its broadest embodiment, the present invention is directed to an isolated protein that comprises a pro-domain of a proneurotrophin. The pro-domain optionally further comprises a mature neurotrophin domain and a connector that joins the pro-domain and the mature neurotrophin domain. The definitions of these terms are as described below.

The definition of the pro-domain is not necessarily that commonly used in the literature. As used herein, the term "pro-domain of a proneurotrophin" or, simply "pro-domain" includes all or part of the amino acid sequence at the N-terminus of a native proneurotrophin, as described above, up to, but not including, the major proneurotrophin cleavage site.

The pro-domain of a proneurotrophin in accordance with the present invention includes all or part of the following amino acid sequences: amino acid residues 1 to approximately 117 of NGF, 1 to approximately 124 of BDNF, 1 to approximately 134 of NT-3, and 1 to approximately 76 of NT-4/5.

In a first embodiment, The pro-domain comprises at least a pro-domain conserved region, the conserved region being an amino acid sequence having at least approximately 85%, preferably at least approximately 90%, more preferably at least approximately 95% (i.e. one mismatch), and most preferably 100% identity to amino acid residues approximately at positions 79-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3, or 43-57 of human NT-4/5. This region will be referred to herein as the pro-domain conserved region, or, simply, the conserved region.

In a second embodiment, the pro-domain of the first embodiment further comprises an amino acid sequence having at least approximately 85%, preferably at least approximately 90%, more preferably at least approximately 95% (i.e. one mismatch), and most preferably 100% identity to amino acid residues approximately at positions 99-117 of human NGF; 106-124 of human BDNF; 116-134 of human NT-3; or 58-76 of human NT-4/5.

In a third embodiment, the pro-domain of the first or second embodiments further comprises an amino acid sequence having at least approximately 85%, preferably at least approximately 90%, more preferably at least approximately 95% (i.e. one mismatch), and most preferably 100% identity to amino acid residues approximately at positions 66-78 of human NGF; 73-90 of human BDNF; 83-100 of human NT-3; or 25-42 of human NT-4/5.

In a fourth embodiment, the pro-domain of the third embodiment further comprises an amino acid sequence having at least approximately 85%, preferably at least approximately 90%, more preferably at least approximately 95% (i.e. one

mismatch), and most preferably 100% identity to amino acid residues approximately at positions 46-65 of human NGF; 57-72 of human BDNF; or 61-82 of human NT-3.

In a fifth embodiment, the pro-domain comprises an amino acid sequence having at least approximately 85%, preferably at least approximately 90%, more preferably at least approximately 95%, and most preferably 100% identity to amino acid residues approximately at positions 46-117 of human NGF; 57-124 of human BDNF; 61-134 of human NT-3; or 25-76 of human NT-4/5.

Any of the pro-domains described above optionally comprise a signal sequence, preferably at the N-terminus. The signal sequence characteristically includes a stretch of hydrophobic amino acid residues that facilitates transport into the endoplasmic reticulum, and facilitates the secretion from cells. The signal sequences of the approximately 18 amino acid residues found at the N-terminus of native NGF, BDNF, and NT-3, and of the approximately 24 amino acid residues found at the N-terminus of native NT-4/5, constitute suitable signal sequences.

The pro-domains of the invention may extend to the N-terminus of any of the native proneurotrophins described above. The full length pro-domain may or may not comprise the signal sequence.

The invention also includes modified proneurotrophin proteins that are cleavage resistant. The modified proneurotrophins comprise a pro neurotrophin domain, a mature neurotrophin domain, and a connector that joins the pro-domain to the mature domain. The pro-domain may be any of the pro-domains mentioned above. The pro-domain is preferably at the N-terminal end of the sequence, and the mature domain is preferably at the C-terminal end.

The mature neurotrophin domain, also referred to herein as the mature domain, includes all or part of the amino acid sequence following the major proneurotrophin cleavage site of a native proneurotrophin. The mature domain may comprise all of the amino acid residues of a native, mature neurotrophin protein.

Alternatively, the mature neurotrophin domain comprises less than all of the amino acid residues of a native, mature neurotrophin, but at least a sufficient number of amino acid residues to confer on the modified proneurotrophin selective binding to p75, and enhanced apoptosis of cells that express p75, relative to the corresponding mature neurotrophin. For example, the amino acid sequence of a mature neurotrophin domain may comprise at least about 20, 40, 60, 80, or 100 amino acid residues from either the N-terminus of a mature neurotrophin protein, the C-terminus of a mature neurotrophin protein, or anywhere else from within the internal sequence of a mature neurotrophin protein.

Therefore, the mature neurotrophin domain in accordance with the present invention includes all or part of the following amino acid sequences: amino acid residues 122 to 241 of NGF, 129 to 247 of BDNF, 139 to 257 of NT-3, and 81 to 210 of NT-4/5.

The modified proneurotrophins of the present invention lack a major proneurotrophin cleavage site. In the modified proneurotrophins, the major cleavage site is replaced by a connector, which is protease cleavage resistant. The connector may be a chemical bond, preferably a covalent or coordinate bond, or any chemical group that is capable of stably joining the pro-domain and the mature domain, and that is protease cleavage resistant.

An example of a chemical group useful as a connector is an oligopeptide. The oligopeptide may be any oligopeptide that is protease cleavage resistant, as long as the modified proneurotrophin retains its biological activity, i.e. greater affinity for p75 receptors than mature neurotrophins, and greater capacity to induce apoptosis of cells that express p75. The connector may be a single amino acid, a dipeptide, a tripeptide, a tetrapeptide, a pentapeptide, a hexapeptide or a peptide chain of any length, preferably less than twenty amino acids, more preferably less than ten amino acids. The connector is preferably a tetrapeptide, as is the major proneurotrophin cleavage site.

Any amino acid or amino acid sequence may be used in the connector. Some examples of suitable amino acid residues include alanine (A), serine (S), threonine (T), and glycine (G).

Any one or more of the amino acid residues in the major proneurotrophin cleavage site may be replaced in order to prevent cleavage. Preferably, one or all of the dibasic residues, arginine (R) and lysine (K), is replaced.

Some examples of suitable oligopeptides include A-A, A-S, S-T, P-G, S-S-S, S-G-A, S-A-A, S-A-P, R-S-A-T, G-G-A-P, and S-S-T-P. Particularly favored oligopeptides include the tetrapeptides: R-S-A-A; R-V-A-A; and A-A-A-A.

A connector that is "resistant to protease cleavage" means that the connector is substantially uncleavable by a protease that is able to cleave a native proneurotrophin as a result of recognition of the major proneurotrophin cleavage site by the protease. Preferably, a connector that is resistant to protease cleavage is completely uncleavable by such a protease.

Examples of proteases that cleave native proneurotrophins include serine proteases. Examples of such serine proteases are the proprotein convertases, such as furin. Accordingly, the connector is substantially uncleavable, and preferably completely uncleavable, by such serine proteases.

The inventors have also surprisingly discovered that certain matrix metalloproteinases (MMPs), such as MMP-3 and MMP-7, and plasmin are also actively involved in the cleavage of proneurotrophins. Plasmin is produced from plasminogen by the action of the plasminogen activator proteinases, such as tissue plasminogen activator (tPA) and urinary plasminogen activator (uPA). Accordingly, the modified proneurotrophins of the invention are further modified to eliminate the cleavage sites for these proteases.

In order to increase their resistance to protease cleavage, the proteins of the invention preferably lack one or more protease cleavage sites in addition to the major cleavage sites, and most preferably lack all protease cleavage sites. Such sites include, for example, dibasic sites, such as R-R, R-K, K-R, and K-K, as well as other cleavage sites, such as L-L sites. Some examples of the sites that the proteins of the invention preferably lack include the following:

The sites in human NGF at positions 49-50 (R-R), 78-79 (K-K), 79-80 (K-R), 80-81(R-R), and 132-134 (E-F-S).

The sites in human BDNF at positions 56-57 (L-T), 106-107 (L-L), 108-109, (F-L), 109-110 (L-L), 111-112 (E-E), 134-135 (R-R), and 137-139 (E-L-S).

The sites in human NT-3 at positions 92-93 (L-L), 105-106 (L-L), 97-98 (R-R) , 148-150 (E-Y-S).

The sites in human NT-4/5 at positions 58-59 (L-L), 60-61 (F-L), 61-62 (L-L), 90-91 (R-R), and 93-95 (E-L-A).

The proteins of the invention comprise all of the isoforms that result from cleavage in any of the pro-domains. For example, the pro-domains comprise isoforms having approximate amino acid residue numbers 1-117, 19-117, 51-117, 81-117, or 82-117 of the human pro-domain of NGF; approximate amino acid residue numbers 1-124, 19-124, 58-124, 110-124, 111-124, or 113-124 of the human pro-domain of BDNF; approximate amino acid residue numbers 1-134, 19-134, or 99-134 of the human pro-domain of NT-3; or approximate amino acid residue numbers 1-76, 25-76, 62-76, or 63-76 of the human pro-domain of NT-4/5. Similarly, the modified proneurotrophins comprise (i) all or part of a mature domain, (ii) a connector, and (iii) approximate amino acid residue numbers 1-117, 19-117, 51-117, 81-117, or 82-117 of the human pro-domain of NGF; approximate amino acid residue numbers 1-124, 19-124, 58-124, 110-124, 111-124, or 113-124 of the human pro-domain of BDNF;

approximate amino acid residue numbers 1-134, 19-134, or 99-134 of the human pro-domain of NT-3; and approximate amino acid residue numbers 1-76, 25-76, 62-76, or 63-76 of the human pro-domain of NT-4/5.

The isoforms described above are derived from cleavage sites present in the pro-domain. In some instances, the cleavage site may occur approximately four amino acids upstream of the sequence recognition site. For example, proteases that recognize LL sites often cleave within four amino acids upstream of the LL sequence recognition site. In other instances, the cleavage site may occur approximately four amino acids downstream of the sequence recognition site. For example, the protease furin often cleaves approximately four amino acids downstream of the sequence recognition site. Therefore, the above-mentioned amino acid residue numbers are approximate.

The examples above all refer to human pro-domains and human mature domains. The comparable positions in the domains of species other than humans can easily be determined by those of ordinary skill. The proneurotrophin sequences of various species is provided in Figures 5B - 5E.

The protease cleavage sites described above may be eliminated completely and not replaced, or may be replaced by any of the oligopeptides described above as being useful as connectors. The oligopeptide is preferably a dipeptide, preferably comprising A, S, T, P, or G. Some examples include A-A, T-A, P-T, and G-A.

The elimination or replacement of the major proneurotrophin cleavage site, or of one or more additional protease cleavage sites in preparing the proteins of the invention, including the modified proneurotrophins, may be achieved by standard techniques well known in the art. Such techniques include, *inter alia*, protein synthesis; synthesis and expression of nucleic acid molecules; and site directed mutagenesis and expression of nucleic acid molecules. See, for example, Kolbeck et al., "Characterisation of neurotrophin dimers and monomers," Eur. J. Biochem. 225, 995-1003 (1994).

Due to the high conservation of neurotrophin sequences, the pro-domain and the mature domain may be from the same vertebrate or from different vertebrates. The vertebrate may be a non-mammalian vertebrate, such as a frog, fish, bird, or chicken. Alternatively, the vertebrate may be a mammal. The mammal may be a farm animal, such as a goat, horse, pig, or cow; a pet animal, such as a dog or cat; a laboratory animal, such as a mouse, rat, or guinea pig; or a primate, such as a monkey, orangutan, ape, chimpanzee, or human. The GenBank accession numbers of sequences of some vertebrate neurotrophins are shown in Table I (A-D) below. The sequences of pro-domains and mature domains are useful in the proteins of the invention, and are incorporated by reference herein.

Moreover, the sequence of the pro-domain and the sequence of the mature domain may be those of the same proneurotrophin or of different proneurotrophins, independent of whether the sequences are from the same or from a different vertebrate. Accordingly, the pro-domain may have the sequence of any proneurotrophin domain. Similarly, and independently, the mature domain may have the sequence of any mature neurotrophin domain. Some examples of such chimeric modified proneurotrophins include:

Pro-NGF-connector-mature BDNF;
Pro-BDNF-connector-mature NT-4/5;
Pro-NT-3-connector-mature NGF;
Pro-BDNF-connector-mature NT-3; and
Pro-BDNF-connector-mature NGF.

The proteins of the invention, such as the modified proneurotrophins described above, including chimeric modified proneurotrophins, may exist as monomers or multimers. The multimers may comprise any number of proneurotrophin units, such as a dimer, trimer, or tetramer. The proneurotrophin units may be all the same proneurotrophin, in which case the multimer is a homomultimer. Alternatively, the multimer may comprise different proneurotrophin units, in which case the multimer is

a heteromultimer. Some examples of heteromultimers include derivatives of NGF-BDGF, NGF-NT-3, BDGF-NT4/5, BDGF-NT-3, and NGF-BDGF-NT4/5.

Table IA: Sequences of Representative Pro and Mature Domains of Pro-NGF (Major Cleavage Sites are Underlined)

Species (GenBank Accession Number)	Pro-NGF Domain	Mature NGF Domain
Human (AAA59931)	MSMLFYTLITAFLLIGVQAEPSSESNVPAGHTIPQVHWTKLQHS�DTALRRARSAP AAAIARVAGQTRNITVDPRLFKKRRLLRSRVLFTSTQPPREADTQDLDFEVGGA APFNRT HR SKR	SSSHPIFHRGEFSVCDSSVWVGDKTTATDIKGKEVTVLGE VNINNSVFQYFFETKCRDPNPVDSGCRGIDSKHWNSYCTT THTFVKALTMGKQAAWRFIRIDTACVCVLSRKAVRRA
Rat (AAA41697)	VHVSMSMLFYTLITAFLLIGVQAEPYTDSNVPEGDSVPEAHWTKLQHS�DTALRRA RSAPAEPIAARVTGQTRNITVDPKLFFKKRRLLRSRVLFTSTQPPPTSSDTLDFQ AHGTISFNRT HR SKR	SSTHPVFHMGFEFSVCDSSVWVGDKTTATDIKGKEVTVLGE VNINNSVFQYFFETKCRAPNPVESGCRGIDSKHWNSYCTT THTFVKALTTDDKQAAWRFIRIDTACVCVLSRKAARRG
Mouse (P01139)	MSMLFYTLITAFLLIGVQAEPYTDSNVPEGDSVPEAHWTKLQHS�DTALRRARSAP TAPIAARVTGQTRNITVDPRLFKKRRLLHSRVLFTSTQPPPTSSDTLDFQAHGT IPFNRT HR SKR	SSTHPVFHMGFEFSVCDSSVWVGDKTTATDIKGKEVTVLAE VNINNSVFRQYFFETKCRASNPNVESGCRGIDSKHWNSYCTT THTFVKALTTDEKQAAWRFIRIDTACVCVLSRKATRRG
Chick (CAA27633)	VHVSMSMLYYTLITAFLLIGVQAAPKSEDNGPLEYPAEHSLLPSTQOSNGQHIKAA PQTHGRFAWMPDGTEDLNIAMDQNFKKRRFRSRVLFTSTQPPVSRKQSTGF LSSAVSLNRTARTKR	TAHPVLHHRGEFSVCDSSVWVGDKTTATDIKGKEVTVLGEV NINNVFKQYFFETKCRDRPPVSSGCRGIDAKHWNSYCTTT HTFVKALTMGKQAAWRFIRIDTACVCVLSRKSGRP
Xenopus (CAA39249)	VDRVMSMLYYTLITAFLLISVQAAAPKTKDHAPARSSAKSRIPHHTRTKSLHHSHG KLEAKEPSYFRNVTVDPKLFRKRKFRSRVLFTSTQPPPLSEDFQHLEYLDDEESL NKTIRAKR	TVHPVLHKGEYSVCDSSVWVGDKTTATDIKGKEVTVLGEV NINNSVFQYFFETKCRDPKPPVSSGCRGIDAKHWNSYCTTT HTFVKALTMGKQAAWRFIRIDTACVCVLSRKGRGRT

Table 1B: Sequences of Representative Pro and Mature Domains of Pro-BDNF (Major Cleavage Sites are Underlined)

Species (GenBank Accession Number)	Pro-BDNF Domain	Mature BDNF Domain
Human (AAA69805)	MTILFLTMVISYFGCMKAAPMKEANIRGQGLAYPGVTRHGTLESVNGPKAGSRG LTSADTFEHVIEELLDEDDQKVRPNEENKADADLYTSRVMLSSQVPLEPPLFLLE EYKNYLDAAANMSMRVRR	HSDPARRGELSVCDSISEWVTAADKKTAVDMSGGTVTVLEK VPVSKGQLKQYFYETKCNPMGYTKEGCRGIDKRHWNSQCRT TQSYVRALTMDSKKRIGWRFFIRIDTSCVCTLTIKRGR
Rat (AAA63483)	MTILFLTMVISYFGCMKAAPMKEANVHGQGNLAYPAVRTHGTLESVNGPRAGSRG LTTSLADTFEHVIEELLDEDDQKVRPNEENHKADADLYTSRVMLSSQVPLEPPLFLLE LEEYKNYLDAAANMSMRVRR	HSDPARRGELSVCDSISEWVTAADKKTAVDMSGGTVTVLEK VPVSKGQLKQYFYETKCNPMGYTKEGCRGIDKRHWNSQCRT TQSYVRALTMDSKKRIGWRFFIRIDTSCVCTLTIKRGR
Mouse (CAA39159)	MTILFLTMVISYFGCMKAAPMKEVNVHGQGNLAYPGVTRHGTLESVNGPRAGSRG LTTSLADTFEHVIEELLDEDDQKVRPNEENHKADADLYTSRVMLSSQVPLEPPLFLLE LEEYKNYLDAAANMSMRVRR	HSDPARRGELSVCDSISEWVTAADKKTAVDMSGGTVTVLEK VPVSKGQLKQYFYETKCNPMGYTKEGCRGIDKRHWNSQCRT TQSYVRALTMDSKKRIGWRFFIRIDTSCVCTLTIKRGR
Chick (AAC42220)	MTILFLTMVISYFGCMKAAPMKEASVRGHGSLAYPGLRTHGTLESLTGPNAGSRG LTSADTFEHVIEELLDEDDQIQPSEENKADADLYTSRVMLSSQVPLEPPLFLLE EYKNYLDAAANMSMRVRR	HSDPARRGELSVCDSISEWVTAAEKKTAVDMSGATVTVLEK VPVPGQLKQYFYETKCNPKGYTKEGCRGIDKRHWNSQCRT TQSYVRALTMDNKKRVGWRFFIRIDTSCVCTLTIKRGR
Bovine (CAA66488)	ILFLTMVISYFGCMKAAPMKEANLRAQGSITYPGVTRHGTLESNMGPKVGSRLT SSSLADTFEHVIEELLDEDDQKVRPSEENKADADMYTSRVMLSSQVPLEPPLFLLE LEEYKNYLDAAANMSMRVRR	HSDPARRGELSVCDSISEWVTAADKKRLAVDMSGGTVTVLEK VPVSKGQLKQYFYETKCNPMGYTKEGCRGIDKRHWNSQCRT TQSYVRALTMDSKKRIGWRFFIRIDTSCVCTLTIKRGR

Table IC: Sequences of Representative Pro and Mature Domains of Pro-NT-3 (Major Cleavage Sites are Underlined)

Species (GenBank Accession Number)	Pro-NT-3 Domain	Mature NT-3 Domain
Human (AAA59953)	MSILFYVIFLAYLRGIQGNMMDQSLPEDSLNSLI IKLIQADILKNKLSKQWVDV KENYQSTLPKAEAPREPERGGPAKSAFQPVIAMDTELLRQRRYNSPRVLLSDST PLEPPPLYLMEDYVGSPVAVNRTSRRKR	YAEHKSHRGEYSVCDSESLWVTDKSSAIDIRGHQVTVLGEI KTGNSPVKQYFYETRCKEARPVKNGCRGIDDKHWSQCKTS QTYVVRALTSENKLVGWRWIRIDTSCVCALSRRKIGRT
Rat (AAA41727)	MSILFYVIFLAYLRGIQGNMMDQSLPEDSLNSLI IKLIQADILKNKLSKQWVDV KENYQSTLPKAEAPREPEQGEATRSEFQPMIATDTELLRQRRYNSPRVLLSDST PLEPPPLYLMEDYVGNPVVTVNRTSPRRKR	YAEHKSHRGEYSVCDSESLWVTDKSSAIDIRGHQVTVLGEI KTGNSPVKQYFYETRCKEARPVKNGCRGIDDKHWSQCKTS QTYVVRALTSENKLVGWRWIRIDTSCVCALSRRKIGRT
Mouse (CAA37348)	MSILFYVIFLAYLRGIQGNMMDQSLPEDSLNSLI IKLIQADILKNKLSKQWVDV KENYQSTLPKAEAPREPEQGEATRSEFQPMIATDTELLRQRRYNSPRVLLSDST PLEPPPLYLMEDYVGNPVVAVNRTSRRKR	YAEHKSHRGEYSVCDSESLWVTDKSSAIDIRGHQVTVLGEI KTGNSPVKQYFYETRCKEARPVKNGCRGIDDKHWSQCKTS QTYVVRALTSENKLVGWRWIRIDTSCVCALSRRKIGRT
Chick (AAA68880)	MSILFYVIFLAYLRGIQSTNMDQSLPEDSMNSLI IKLIRADILKNKLSKQWMDV KENYQNIVQKVEDHQEMDGDENVKSDFPVISMDTDLRQRRYNSPRVLLSDNT PLEPPPLYLTEDYVGSSVVLNRTSRRKR	YAEHKSHRGEYSVCDSESLWVTDKSSAIDIRGHQVTVLGEI KTGNSPVKQYFYETRCKEARPVKNGCRGIDDKHWSQCKTS QTYVVRALTSENKLVGWRWIRIDTSCVCALSRRKIGRT
Xenopus (AAB17723)	MSILFYVMFLPYLCGIHATNMDKRNLPENSMNSLFIKLIQADLLKNKISKQTVDT KENHQSTIPKQPQILLDLDDGDDNMKQDFQPVISLEAELVKQKQRRYKSPRVLLSD SLPLEPPPLYLMDDYIGHSTVTVNNRTSRRKR	FAEHKSHRGEYSVCDSESLWVTDKMNNAIDIRGHQVTVLGEI KTGNSPVKQYFYETRCKEARPVKNGCRGIDDKHWSQCKTS QTYVVRALTSENKLVGWRWIRIDTSCVCALSRRKIGRSKNYL DAANMSMRVRR

Table ID: Sequences of Representative Pro and Mature Domains of Pro-NT-4/5 (Major Cleavage Sites are Underlined)

Species (GenBank Accession Number)	Pro-NT-4/5 Domain	Mature NT-4/5 Domain
Human (AAA60154)	MLPLPSCSLPILLFLLPSVPPIESQPPPTLLPFLAPEWDLLSPRVVLSRGAP AGPPLLFLLEAGAFRESAGAPANRR <u>RR</u>	GVSETAPASRRGELAVCDAVSGWVTDRTAVDLRGREVEVLG EVPAAGGSPLRQYFFETRCKADNAEEGGPGAGGGGCGVDRR HWVSECKAKQSYVRALTADAQGRVGRWIRIDTACVCTLLSR TGRA
Rat (AAA41728)	MLPRHSCSLLLFLLLPSPVMEPQPPSTLLPFLAPEWDLLSPRVALSRTGA GPPLLFLLEAGAYGEPAGAPANRR <u>RR</u>	GVSETAPASRRGELAVCDAVSGWVTDRTAVDLRGREVEVLG EVPAAGGSPLRQYFFETRCKAESAGEGGPGVGGGCGVDRR HWLSECKAKQSYVRALTADSQGRVGRWIRIDTACVCTLLSR TGRA
Xenopus (CAA82906)	MILRLYAMVISYCCAI CAAPFQSRRTDLDYGPDKTSEASDRQSVNNFHVLP NGFFPDLSSTYSYSSMAGKDWNLVSPRVTLSSSEPSGPPLLFLSEETVHVHPEPAN KTSRL <u>KR</u>	ASGSDSVLSRRGELSVCDNVNVTDKRTAVDDRGKIVTM SEIQTLTGPLKQYFFETKCNPSGSTTRGCRGVDDKKQWISECK AKQSYVRALTIDANKLVGRWIRIDTACVCTLLSRTGRT

In another embodiment, the invention comprises a protein having at least a pro-domain of a proneurotrophin. Any of the pro-domains described above are suitable. The protein may be used as an intermediate to make the modified proneurotrophins described above, or may be used by itself as a substitute for the modified proneurotrophins in the methods of use described below. The protein optionally comprises additional amino acid residues, and may lack a mature domain. The protein further optionally contains a connector, as described above, and/or a major proneurotrophin cleavage site.

The pro-domain and the mature domain of the proteins of the invention may further comprise one or more groups commonly associated with amino acid chains. The groups may, for example, result from acetylation, phosphorylation, sulfation, glycosylation or lipidation. Further, the amino acid chain may be chemically bonded to additional peptide and non-peptide moieties. The non-peptide moiety may, for example, be a detectable label, a purification tag, such as a His tag, or a biologically active moiety such as an enzyme or a toxin.

The proneurotrophins of the invention include homologs of naturally occurring or native proneurotrophins. A homolog of a native proneurotrophin may be, for example, a substitution mutant, a mutant having an addition or insertion, or a deletion mutant of the protein. Substitutions in a sequence of amino acids are preferably with equivalent amino acids. Groups of amino acids known to be of equivalent character are listed below:

- (a) Ala(A), Ser(S), Thr(T), Pro(P), Gly(G);
- (b) Asn(N), Asp(D), Glu(E), Gln(Q);
- (c) His(H), Arg(R), Lys(K);
- (d) Met(M), Leu(L), Ile(I), Val(V); and
- (e) Phe(F), Tyr(Y), Trp(W).

Any substitutions, additions, and/or deletions in an amino acid sequence are permitted provided that the protein of the invention continues to satisfy the functional

criteria described herein. An amino acid sequence that is substantially identical to another sequence, but that differs from the other sequence by means of one or more substitutions, additions, and/or deletions, is considered to be an equivalent sequence.

In order to compare a first amino acid or nucleic acid sequence to a second amino acid or nucleic acid sequence for the purpose of determining homology, the sequences are aligned so as to maximize the number of identical amino acid residues or nucleotides. The sequences of highly homologous proteins and nucleic acid molecules can usually be aligned by visual inspection. If visual inspection is insufficient, the nucleic acid molecules may be aligned in accordance with methods known in the art. Examples of suitable methods include those described by George, D.G. et al., in *Macromolecular Sequencing and Synthesis, Selected Methods and Applications*, pages 127-149, Alan R. Liss, Inc. (1988), such as formula 4 at page 137 using a match score of 1, a mismatch score of 0, and a gap penalty of -1.

Preferably, less than 15%, more preferably less than 10%, and still more preferably less than 5% of the number of amino acid residues in the sequence of a pro-domain or a mature domain are different (i.e., substituted for, inserted into, or deleted from) from the amino acid residues in the sequence of the corresponding domain of a naturally occurring proneurotrophin to yield the high affinity p75-binding protein of the invention. More preferably still, less than 3%, yet more preferably less than 2% and optimally less than 1% of the number of amino acid residues in a sequence are different from those in a naturally occurring sequence.

The proteins of the invention, including the modified proneurotrophins of the invention, are isolated. As used herein, the term "isolated" means substantially free from other biological components, as well as from materials that are used in preparation, isolation, characterization or purification of proteins. Some examples of other biological components include cellular components, culture media or components (including conditioned media and components thereof), affinity binding agents, such as immunoconjugates or antibodies and other serum components. Examples of materials that are used in preparation, isolation, or purification of

proteins include separation media or membranes, such as nitrocellulose, chromatographic matrices, and electrophoretic gel media, including for instance, polyacrylamide and detergents, such as sodium dodecyl sulfate (SDS).

Preferably, the isolated material is at least about 25% to about 90% pure, i.e. free from other proteins and nucleic acid molecules. More preferably, the isolated material is at least about 50% to about 90% pure. Optimally, the isolated material is at least about 75% to about 90% pure.

Most preferably, the proteins of the invention, including the modified proneurotrophin, are purified. As used herein, the term "purified" means essentially pure as demonstrated by single band purity on electrophoresis in SDS-polyacrylamide gels (SDS PAGE). Preferably, the purified material is at least about 90% to about 99.9% pure. More preferably, the purified material is at least about 95% to about 99.9% pure. Optimally, the purified material is at least about 99% to about 99.9% pure.

Nucleic acids encoding proneurotrophins, vectors, hosts, site directed mutagenesis:

In a particular embodiment, the invention provides a nucleic acid molecule that encodes any of the proteins mentioned above, such as the pro-domains and the modified proneurotrophin resistant to cleavage by one or more proteases. Preferably, the sequence of the nucleic acid molecule exists in nature, preferably in a mammalian organism, more preferably, in a human. The encoded protein optionally further comprises a signal sequence and may or may not also include all or part of the mature neurotrophin domain. The nucleic acid may be a DNA molecule, such as for example cDNA or genomic DNA, or alternatively the nucleic acid may be an RNA molecule, such as for example mRNA.

The nucleic acid of the invention may be incorporated into a recombinant vector for replication to amplify the nucleic acid, or for expression and

isolation/purification of the encoded protein. The recombinant vector may be any recombinant vector, such as a plasmid, a cosmid or a phage. Recombinant vectors have an origin of replication from which copying of the vector and incorporated nucleic acid sequences is initiated. The vector may further include a selectable marker, such as for instance a drug resistance marker, a detectable gene marker or an origin of replication for a second host cell and also a multiple cloning site for ease of manipulation of the inserted nucleic acid.

Pharmaceutical compositions:

In a preferred embodiment, the proteins of the invention, including the pro-domains and the cleavage resistant proneurotrophins described above, are incorporated in pharmaceutical compositions suitable for use as a medicament, for human or animal use. The pharmaceutical compositions may be for instance, in an injectable formulation, a liquid, cream or lotion for topical application, an aerosol, a powder, granules, tablets, suppositories or capsules, such as for instance, enteric coated capsules etc. The pharmaceutical compositions may also be delivered in or on a lipid formulation, such as for instance an emulsion or a liposome preparation. The pharmaceutical compositions are preferably sterile, non-pyrogenic and isotonic preparations, optionally with one or more of the pharmaceutically acceptable additives listed below.

Pharmaceutical compositions of the cleavage resistant proteins of the invention are preferably stable compositions which may comprise one or more of the following: a stabilizer, a surfactant, preferably a nonionic surfactant, and optionally a salt and/or a buffering agent. The pharmaceutical composition may be in the form of an aqueous solution, or in a lyophilized form.

The stabilizer may, for example, be an amino acid, such as for instance, glycine; or an oligosaccharide, such as for example, sucrose, tetralose, lactose or a dextran. Alternatively, the stabilizer may be a sugar alcohol, such as for instance, mannitol; or a combination thereof. Preferably the stabilizer or combination of

stabilizers constitutes from about 0.1% to about 10% weight for weight of the proneurotrophin.

The surfactant is preferably a nonionic surfactant, such as a polysorbate. Some examples of suitable surfactants include Tween20, Tween80; a polyethylene glycol or a polyoxyethylene polyoxypropylene glycol, such as Pluronic F-68 at from about 0.001% (w/v) to about 10% (w/v).

The salt or buffering agent may be any salt or buffering agent, such as for example, sodium chloride, or sodium/potassium phosphate, respectively. Preferably, the buffering agent maintains the pH of the pharmaceutical composition in the range of about 5.5 to about 7.5. The salt and/or buffering agent is also useful to maintain the osmolality at a level suitable for administration to a human or an animal. Preferably the salt or buffering agent is present at a roughly isotonic concentration of about 150mM to about 300mM.

The pharmaceutical compositions of the present invention may additionally contain one or more conventional additive. Some examples of such additives include a solubilizer such as for example, glycerol; an antioxidant such as for example, benzalkonium chloride (a mixture of quaternary ammonium compounds, known as "quats"), benzyl alcohol, chlorethone or chlorobutanol; anaesthetic agent such as for example a morphine derivative; or an isotonic agent etc., such as described above. As a further precaution against oxidation or other spoilage, the pharmaceutical compositions may be stored under nitrogen gas in vials sealed with impermeable stoppers.

Methods of Use:

The proteins of the invention, especially when incorporated into pharmaceutical compositions as described above, are useful in methods for the treatment of certain conditions in a mammal. The conditions are mediated by, or involve, cells that express the p75 receptor. The mammal may be a farm animal, such

as a goat, horse, pig, or cow; a pet animal, such as a dog or cat; a laboratory animal, such as a mouse, rat, or guinea pig; or a primate, such as a monkey, orangutan, ape, chimpanzee, or human.

For conditions characterized by undesirable cell growth, it is beneficial to induce apoptosis. For conditions characterized by undesirable cell death, it is beneficial to inhibit apoptosis. The invention includes both types of methods.

Methods To Induce Apoptosis

In one embodiment, the invention relates to a method for preventing or inhibiting growth of unwanted cells that express p75 receptors. Unwanted cell growth occurs, for example, in malignant cells, such as tumor cells, and in atherosclerotic plaques, especially in the smooth muscle cells of atherosclerotic plaques and vascular ischemias. The malignant cells may, for example, be melanoma cells, lymphoma cells, leukemic cells, prostate cells, pancreatic cells, cells of the testis, lung, brain or heart, or cells of the nervous system, such as cells of the central or peripheral nervous systems. Malignant nervous system cells include malignant neurons and glia cells, such as, for example, medulloblastomas, astrocytomas, and malignant oligodendrocytes.

Without wishing to be bound by theory, it is believed that the cleavage resistant proteins bind the p75 receptor on the unwanted cells, initiating a commitment to programmed cell death (apoptosis). The invention provides methods of treatment of conditions that are mediated by, or that involve, cells that express the p75 receptor. At least three embodiments of the methods lead to enhanced apoptosis:

The first embodiment involves the administration of a protein of the invention *in vivo* to a human or animal undergoing treatment or otherwise in need thereof. As mentioned above, the proteins of the invention either lack a mature domain or are resistant to one or more proteases that would otherwise be effective in the cleavage of the protein to a mature neurotrophin or to a neurotrophin form with residual trk-binding activity. The protein binds the p75 receptor on the surface of cells that are

involved in or mediate the condition. The binding of the cleavage resistant proneurotrophin to the p75 receptor induces apoptosis of the cell.

The second embodiment involves the administration to a mammal of an inhibitor of a protease that cleaves the major protease cleavage site and/or other cleavage sites of a proneurotrophin. The inhibition reduces or prevents the processing of proneurotrophin to mature neurotrophin. The proneurotrophin binds the p75 receptors on the surface of the cells involved in or mediating the condition, disease or disorder being treated. Binding of the proneurotrophin to the p75 receptors induces apoptosis, as described above.

The third embodiment involves a combination of one of the above embodiments with administration of an inhibitor of trk activation. This additional treatment inhibits signaling initiated by any trk receptors that may be present. Activation is initiated by neurotrophin binding and autophosphorylation of the trk receptor. The inhibitor of trk activation blocks trk autophosphorylation, and thereby also blocks subsequent kinase activation in the signal transduction pathways activated by trk.

These methods are effective for any cells that express trk receptors as well as those that express the p75 receptor. As shown in Example 7, for example, superior cervical ganglia neurons coexpress both p75 and trk A receptors. Treatment of the neurons with pro-NGF resulted in cell death. Treatment with mature NGF resulted in very little cell death. Therefore, any of the molecules of the invention are capable of inducing p75-mediated apoptosis *in vitro* and *in vivo* in both the presence and absence of trk.

The methods are especially effective in cells in which trk receptors, if present, are not activated. The level of expression of the p75 receptor may be a normal level of expression, a higher than normal level of expression or even a lower than normal level of expression of p75.

A normal level of p75 receptor expression on the surface of a cell is from about 50,000 to about 100,000 such receptors per cell. A higher than normal level of p75 receptor expression includes all cells expressing more than about 100,000 p75 receptors per cell, preferably more than about 150,000 of the p75 receptors per cell; more preferably more than about 200,000 p75 receptors per cell; still more preferably more than about 250,000 p75 receptors per cell and optimally up to about 1,000,000 or more p75 receptors per cell. Cells expressing a lower than normal level of p75 receptors typically have from about 100 to about 50,000 p75 receptors per cell.

In yet another particular embodiment, the invention provides a method for inhibiting activation of the trk receptors of a cell of a mammal in need of such treatment. The method includes the step of administering an effective amount of an inhibitor that inhibits a protease that cleaves the major protease cleavage site of a proneurotrophin. The inhibition of the cleavage of proneurotrophin to mature neurotrophin has the effect of preventing the activation of the cognate trk receptors of the cell by the mature neurotrophin.

The protease inhibitor in any of the methods mentioned above may be any inhibitor that inhibits a protease that cleaves the major protease cleavage site of a proneurotrophin. Some classes of proteases include serine proteases, or pro-protein convertases, such as for instance a furin. Alternatively, the protease that cleaves the major protease cleavage site of a proneurotrophin may be plasmin, (activated by a plasminogen activator such as tissue plasminogen activator or urinary plasminogen activator) or a matrix metalloproteinase, such as for instance, MMP-3 or MMP-7.

Some examples of furin inhibitors include, for example, Furin Inhibitor I (Decanoyl-Arg-Val-Lys-Arg-CMK) and Furin Inhibitor II (hexa-(D) arginine), both of which are available from Calbiochem. Some examples of plasmin inhibitors include, for example, epsilon amino caproic acid, tramexanic acid, alpha-2 macroglobulin or aprotinin (See *Anes. Anal.* 2001, 92: 775 and *Ann Thorac. Surg.* 2000, 70: 1300 for details of these inhibitors). Some examples of inhibitors of matrix metalloproteinases include tetracycline derivatives and other non-peptidic inhibitors

such as AG3340 (from Agouron), BAY 12-9566 (from Bayer), BMS-275291 (from Bristol-Myers Squibb) and CGS 27023A (from Novartis) or the peptidomimetics marimastat and Batimastat (from British Biotech), and the MMP-3 (stromelysin-1) inhibitor, Ac-RCGVDP-NH₂ available from Calbiochem (San Diego, CA). See Hidalgo et al. 2001. *J. Natl. Can. Inst.* 93: 178-93 for a review of MMP inhibitors in cancer therapy.

In yet another embodiment, the invention provides a method for inducing apoptosis of a cell of a mammal in need thereof, the cell being susceptible to initiation of apoptosis by the binding of proneurotrophin to p75 receptors. The method includes the step of administering to the mammal an effective amount of a combination of a protein of the invention along with an inhibitor of trk activation. The inhibitor of trk activation may be any inhibitor of trk activation. Some examples of trk activation include a kinase inhibitor such as for instance, an indolecarbazole derivative. Examples of indolecarbazole derivatives include the kinase inhibitor K252a described by Ruggeri et al. 1999. *Curr. Med. Chem.* 6:845-57. The compound K252a from Cephalon is currently in clinical trials as a candidate for the treatment of pathological conditions of the prostate gland, e.g., benign prostatic hypertrophy or prostate cancer.

In yet a further embodiment, the invention provides a method for cleaving a proneurotrophin protein to yield a mature neurotrophin. The method comprises contacting the proneurotrophin protein with a particular matrix metalloproteinase. Specifically, the proneurotrophin protein is contacted with MMP-3 or MMP-7. Alternatively, the proneurotrophin protein is contacted with plasmin. Preferably, the proneurotrophin protein is pro-BDNF.

In a further particular embodiment, the invention provides a pharmaceutical composition comprising a protein of the present invention in combination with an inhibitor that inhibits a protease that cleaves the major protease cleavage site of a proneurotrophin. The combination is preferably in a formulation suitable for use as a medicament for human or animal use as described above.

In another further particular embodiment, the invention provides a method of treating a condition, disease or disorder mediated by or involving cells with any appreciable level of p75 receptor expression. The method involves administering an effective amount of a pharmaceutical composition comprising the above-recited combination of a protein of the invention in combination with an inhibitor that inhibits a protease that cleaves the major protease cleavage site of a proneurotrophin.

In yet a further particular embodiment, the invention provides a method of treating a condition, disease or disorder mediated by or involving cells with any appreciable level of p75 receptor expression, by administering an effective amount of a pharmaceutical composition comprising a protein of the invention in combination with an inhibitor that inhibits trk activation.

Methods of Inhibiting Apoptosis

In another embodiment, the invention relates to a method for inhibiting apoptosis of a cell in a mammal in need thereof. The method comprises inhibiting unwanted binding of a proneurotrophin to a p75 receptor.

The proneurotrophin may be any pro-neurotrophin, e.g., pro-NGF, pro-BDNF, pro-NT-3, or pro-NT-4/5. In this specification, a proneurotrophin refers to an entire proneurotrophin, or to any of the proneurotrophin isoforms that results from cleavage of a pro-domain, such as the isoforms described above.

The cell may be any cell that expresses p75, and that undergoes p75-mediated apoptosis. Some examples of suitable cells include cells of the nervous system, testis, lung, brain, and heart, such as cardiomyocytes.

Cells of the nervous system include the various cells of the central nervous system and of the peripheral nervous system. For example, the cells may be neurons or glia cells. Some examples of glia cells include oligodendrocytes, Schwann cells and astrocytes.

Moreover, p75 receptors are present in hair follicles of humans. Typically, the p75 receptors are on keratinocytes and epithelial cells of the outer root sheath.

In a further embodiment, the present invention relates to a method for inhibiting and treating apoptosis-mediated hair follicle regression (e.g. hair loss and baldness) in a human in need thereof. The method comprising administering to the human an effective amount of a molecule that inhibits the binding of a proneurotrophin to a p75 receptor. Other than the part of the body treated, the methods described elsewhere in this application for inhibiting apoptosis, including modes of administration, may be used in the present embodiment. The preferred mode of administration is topical administration to the skin in the area of the hair follicle regression.

The method comprises administering to a mammal a molecule that inhibits the binding of a proneurotrophin to a p75 receptor. A molecule is considered to inhibit the binding of a proneurotrophin to a p75 receptor if the molecule causes a significant reduction in such binding, and the reduction in binding causes a significant reduction in apoptosis. A reduction is considered significant, for example, if the reduction is at least about 10%, preferably at least about 25%, more preferably at least about 75%, and most preferably at least about 90%.

The molecule may be any molecule that inhibits the binding of a proneurotrophin to a p75 receptor. In one embodiment, the molecule binds specifically to the p75 receptor, and thereby blocks binding of the proneurotrophin to a p75 receptor, but does not activate the p75 receptor.

Some suitable examples of such molecules comprise an antibody hypervariable region that binds specifically to p75 receptors. The hypervariable region may be used alone, or may be part of an entire antibody variable region. The variable region may further comprise an antibody constant region. These molecules may be in the form of antibodies, or any fragment of antibodies, as described above.

The molecule that binds specifically to the p75 receptor may also be a small molecule or an oligopeptide. The small molecule or oligopeptide binds specifically to the p75 receptor, blocks binding of the proneurotrophin to a p75 receptor, but does not lead to the biological activity that is caused by binding of the p75 receptor to the proneurotrophin.

Such small molecules and oligopeptides can be discovered by methods well known in the art. Typically, discovering such molecules involves providing a cell that expresses p75, providing a small molecule or oligopeptide to be tested, and determining whether the small molecule or oligopeptide to be tested binds to a p75 receptor and, optionally, results in the biological activity caused by binding of a proneurotrophin to a p75 receptor. If the molecule binds with high affinity to the p75 receptor, it is a candidate for use in inhibiting apoptosis. If the molecule binds to the p75 receptor with high affinity and blocks binding of the proneurotrophin to a p75 receptor, it is a stronger candidate. If, in addition to blocking binding, the molecule also fails to cause the biological activity expected from activating a p75 receptor, e.g. apoptosis, the molecule is a candidate for pre-clinical or clinical trials.

The oligopeptide has at least approximately four amino acid residues, preferably at least approximately five amino acid residues, and more preferably at least approximately six amino acid residues. The maximum number of amino acid residues is not important, as long as the oligopeptide has the desirable properties mentioned above. The oligopeptide may be linear or cyclic. A cyclic peptide is a linear protein in which a carboxy group, usually the C-terminal carboxy group, forms an amide bond with an amino group, usually the N-terminal amino group.

Some examples of oligopeptides include:

S/T-P/S-R-V-(Z)_z

S/T-P/S-R-V-L/M/V-(Z)_z

S/T-P/S-R-V-L/M/V-F/L-(Z)_z

S/T-P/S-R-V-L/M/V-F/L-S-(Z)_z

Wherein Z represents any alpha amino acid and z represents any number from 0 to approximately 20, preferably from 0 to approximately 10, and more preferably from 0 to approximately 5. Any of these oligopeptides may be cyclic.

Small molecules include organic compounds, organometallic compounds, salts of organic and organometallic compounds, saccharides, amino acids, and nucleotides. Small molecules typically have molecular weights less than approximately 450 Daltons. Small molecules include compounds that are found in nature as well as synthetic compounds.

In addition to molecules that bind specifically to p75 receptors, the present invention includes molecules that bind specifically to the proneurotrophin. The proneurotrophin can be any proneurotrophin, such as the native proneurotrophin molecules identified above. The molecules preferably bind with substantially greater affinity, and preferably bind exclusively, to a proneurotrophin, relative to a mature neurotrophin.

Some suitable examples of molecules that bind specifically to proneurotrophins include molecules that comprise the extracellular domain of a p75 receptor, but that lack the intracellular and trans-membrane domains of a p75 receptor. The extracellular domain may be in a soluble form, or in the form of receptor-Ig chimeras known as receptor bodies or receptobodies. Preferred receptor bodies are divalent homodimers that contain the ligand-binding domain of a receptor followed by the hinge and Fc region of an Ig, such as Ig1. The Ig is preferably human Ig. Receptor bodies can be made by methods well known in the art. See, for example, Binder et al. 1999. *J. Neurosci.* 19:1424-1436 and Marcus et al. 1996. *Dev. Biol.* 180:786-789.

Alternatively, the molecule that binds specifically to the proneurotrophin may comprise an antibody hypervariable region that binds specifically to a proneurotrophin. The hypervariable region may further comprise an entire antibody

variable region. The antibody variable region may further comprise an antibody constant region. Accordingly, the molecule that comprises an antibody hypervariable region may be any of the antibodies (including chimerized and humanized antibodies) and antibody fragments (including single chain antibodies) described below.

The molecules described above that bind specifically to proneurotrophins, such as the extracellular p75 receptors and molecules containing a hypervariable region described above, may be designed to bind to proneurotrophin monomers or to proneurotrophin multimers. The multimer may be any of the homomultimers and heteromultimers described above.

Administration of a cocktail of more than one molecule that inhibits the binding of a proneurotrophin to a p75 receptor is especially desirable. The molecules in the cocktail may comprise receptor bodies, antibodies, or a combination of receptor bodies and antibodies.

The cocktail may, for example, comprise one or more molecules that bind specifically to one, two, three, or all of the proneurotrophins. The cocktail may further comprise one or more molecules that binds specifically to the p75 receptor.

In another embodiment, the molecule that inhibits the binding of a proneurotrophin to a p75 receptor is a protease that cleaves the proneurotrophin to form a mature neurotrophin. The protease may be any of the proteases that cleave proneurotrophins, such as those described above.

The mammal in need of inhibiting apoptosis is generally a human who suffers from a condition associated with undesired apoptosis due to binding of a proneurotrophin to a p75 receptor. In this specification, a condition means any pathological state, such as, for example, a disease, an injury, or any other state that varies from a normal, proper, or healthy state. A condition associated with undesired apoptosis means any condition to which apoptosis contributes either primarily or secondarily, or either directly or indirectly.

The condition may involve normal expression in the mammal of the p75 receptor and the proneurotrophin. Usually, the condition involves overexpression of the proneurotrophin or of the p75 receptor in the cell undergoing apoptosis, or both.

Conditions suitable for treatment in accordance with this embodiment of the invention, may, for example, be the result of a nervous system injury or an environmental insult. The condition may, for example, be the result of hypoxic ischemia. Hypoxic ischemia may, for example, be caused by a stroke or by a heart attack.

The condition amenable to treatment by the present invention may be caused by a viral infection or a microbial infection. The microbial infection may be a bacterial infection. Some example of conditions caused by a viral infection or a microbial infection include meningitis, encephalitis, or abscesses.

Further examples of conditions that can be treated by the present invention include neurodegenerative and autoimmune disorders. Some examples of such disorders include Alzheimer's Disease, multiple sclerosis, familial dysautonomia, ataxia telangiectasia, Charcot-Marie-Tooth disease, Adreno leuko dystrophy, spinal muscular atrophy, Friedreich's ataxia.

The condition may also be a condition that causes convulsions. An example of such a condition is epilepsy.

Antibodies

The present invention provides antibodies raised against the proteins, conjugates, and complexes described above. In this specification, an antibody is defined broadly as a protein that binds specifically to an epitope. Antibodies that bind specifically to an epitope may comprise an antibody hypervariable region. The hypervariable region may further comprise an entire antibody variable region. The antibody variable region may further comprise an antibody constant region. The

molecule that comprises an antibody hypervariable region may be an antibody including a whole antibody, an antibody fragment, a chimerized antibody or a humanized antibody. The antibody may be polyclonal or monoclonal.

Suitable variable and hypervariable regions of non-human antibodies may be derived from antibodies produced by any non-human mammal in which monoclonal antibodies are made. Suitable examples of mammals other than humans include, for example, rabbits, rats, mice, horses, goats, or primates. Preferably, the antibodies are human antibodies. The antibodies may be produced in a transgenic mouse. An example of such a mouse is the so-called XenoMouse™ (Abgenix, Freemont, CA) described by Green, LL., "Antibody Engineering Via Genetic Engineering of the Mouse: XenoMouse Stains are a Vehicle for the Facile Generation of Therapeutic Human Monoclonal Antibodies," *J. Immunol. Methods*, 10;231(1-2):11-23(1999).

Antibody fragments have binding characteristics that are the same as, or are comparable to, those of the whole antibody. Suitable fragments of the antibody include any fragment that comprises a sufficient portion of the hypervariable (i.e. complementary determining) region to bind specifically, and with sufficient affinity, to proneutrophins or p75.

The preferred fragments are single chain antibodies. Single chain antibodies are polypeptides that comprise at least the variable region of the heavy chain of the antibody and the variable region of the light chain, with or without an interconnecting linker.

A chimerized antibody comprises the variable region of a non-human antibody and the constant region of a human antibody. A humanized antibody comprises the hypervariable region (CDRs) of a non-human antibody. The variable region other than the hypervariable region, e.g. the framework variable region, and the constant region of a humanized antibody are those of a human antibody.

The antibodies and functional equivalents may be members of any class of immunoglobins, such as: IgG, IgM, IgA, IgD or IgE, and the subclass thereof. The

functional equivalents may also be equivalents of combinations of any of the above classes and subclasses.

Modes of Administration

An effective amount of the protein of the invention, preferably in a pharmaceutical composition, may be administered to a human or an animal in need thereof by any of a number of well-known methods for use in any of the therapeutic methods described above. For example, the protein may be administered systemically or locally, for example by injection.

The systemic administration of a protein of the invention may be by intravenous, subcutaneous, intraperitoneal, intramuscular or intrathecal administration for treatment of a neural cell condition. Some examples of neural conditions include medulloblastoma, astrocytoma, a malignant dendrocyte or other cancerous condition of a neural cell of either the central nervous system (CNS) or the peripheral nervous system.

Alternatively, the protein of the invention may be applied topically in appropriate situations. Such situations include, exposed tissue to be treated. Some examples of exposed tissue include exposed metastatic tissue, as for example in a melanoma. Other exposed cancerous tissue includes cancerous breast tissue. The protein may also be delivered to the scalp of a person to inhibit hair loss due to p75-mediated hair follicle regression.

Alternatively, nucleic acid molecules of the invention may be incorporated into recombinant vectors suitable for use in gene therapy. The vector suitable for use in gene therapy may be any vector that comprises a nucleic acid sequence capable of expressing a protein of the invention in a mammal, especially a human, in need of such therapy. The suitable vector may be for example a viral vector, such as an adenovirus vector or an adeno-associated virus (AAV) vector. See for example: Ledley 1996. *Pharmaceutical Research* 13:1595-1614 and Verma et al. *Nature* 1997. 387:239-242.

In another alternative method, nucleic acid molecules of the invention may be administered as naked DNA. The naked DNA may be administered directly to the cells of an organ, tissue or anatomical region most affected by a disorder, condition or disease mediated by or involving cells expressing the p75 receptor. The expressed protein binds to the p75 receptor and induces apoptosis of the cell, thereby preventing any further pathological growth or proliferation of the cell.

An effective amount of a pharmaceutical composition of the invention is any amount that is effective to reduce, stabilize or ameliorate the progression of the condition to be treated. The relevant amount, usually expressed in mg/kg is determined by routine methods in clinical trials by those of skill in the art.

Screening For Conditions

In another embodiment, the invention relates to a method for screening a human patient for a condition associated with undesired apoptosis. The method comprises using a probe to determine the level of at least one proneurotrophin or a proneurotrophin-p75 conjugate in a biological sample.

The biological sample can be any sample taken from the human patient. The biological sample may, for example, be blood, urine, hair, cheek scrapings, semen, tissue biopsy, or saliva.

The proneurotrophin may be any pro-neurotrophin, e.g., pro-NGF, pro-BDNF, pro-NT-3, or pro-NT-4/5. In this specification, a proneurotrophin refers to an entire proneurotrophin, or to any of the proneurotrophin isoforms that results from cleavage of a pro-domain. See above.

The proneurotrophin-p75 conjugate is any proneurotrophin associated with the p75 receptor.

The method comprises determining whether elevated levels of proneurotrophin or proneurotrophin-p75 conjugates are present in the biological sample. The elevated levels indicate the existence of the suspected condition.

In this specification, an elevated level of proneurotrophins means a significantly greater level relative to a human who does not have the condition. A level is significantly greater if the level is at least about 10%, preferably at least about 25%, more preferably at least about 50%, even more preferably at least about 75%, and most preferably at least about 100% greater than a human who does not have the condition. It is not necessary to determine the level of proneurotrophins in a human who does not have the condition each time.

The probe recognizes at least one proneurotrophin or proneurotrophin-p75 conjugate. In this specification, a probe may, for example, be an antibody, a soluble p75 receptor or a receptor body as described elsewhere in this specification.

Screening Probes

The probe used to determine the level of at least one proneurotrophin or a proneurotrophin-p75 conjugate in a biological sample may be any molecule that binds specifically to a proneurotrophin or a conjugate. Some examples of probes that recognize proteins include antibodies, soluble receptors or receptor bodies as described elsewhere in this specification.

Alternatively, the probe may detect nucleic acid molecules that encode a proneurotrophin. The probe may be an oligonucleotide complementary to the nucleic acid sequence that encodes a proneurotrophin. These oligonucleotide probes are typically designed to detect proneurotrophin mRNA. It should be noted, however, that elevated levels of proneurotrophin mRNA suggest, but are not necessary indicative of, elevated levels of proneurotrophins. The possibility of cleavage of the proneurotrophins into mature neurotrophin must be considered.

The probes described above are optionally labelled in accordance with methods known in the art. The label may be a radioactive atom, an enzyme, or a chromophoric moiety.

Methods for labelling antibodies have been described, for example, by Hunter and Greenwood 1962. *Nature* 144:945 and by David et al. 1974. *Biochemistry* 13:1014-1021. Additional methods for labelling antibodies have been described in U.S. Patent Nos. 3,940,475 and 3,645,090 and in Harlow, E. and Lane, D., *Using Antibodies, A Laboratory Manual*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York (1999).

Methods for labelling oligonucleotide probes have been described, for example, by Leary et al., 1983. *Proc. Natl. Acad. Sci. USA* 80:4045; Renz and Kurz 1984. *Nucl. Acids Res.* 12:3435; Richardson and Gumpert 1983. *Nucl. Acids Res.* 11:6167; Smith et al. 1985. *Nucl. Acids Res.* 13:2399; Meinkoth and Wahl, *Anal.* 1984. *Biochem.* 138:267; and Ausubel, F.M. et al. (Eds.) *Current Protocols in Molecular Biology*, John Wiley & Sons, Inc., New York, 1999.

The label may be radioactive. Some examples of useful radioactive labels include ^{32}P , ^{125}I , ^{131}I , ^{35}S , ^{14}C , and ^3H . Use of radioactive labels have been described in U.K. 2,034,323, U.S. 4,358,535, and U.S. 4,302,204.

Some examples of non-radioactive labels include enzymes, chromophores, atoms and molecules detectable by electron microscopy, and metal detectable by their magnetic properties.

Some useful enzymatic labels include enzymes that cause a detectable change in a substrate. Some useful enzymes and their substrates include, for example, horseradish peroxidase (pyrogallol and o-phenylenediamine), beta-galactosidase (fluorescein beta-D-galactopyranoside), and alkaline phosphatase (5-bromo-4-chloro-3-indolyl phosphate/nitro blue tetrazolium). The use of enzymatic labels have been described in U.K. 2,019,404, EP 63,879, in Ausubel, F.M. et al. (Eds.), *Current*

Protocols in Molecular Biology, John Wiley & Sons, Inc., New York (1999), and by Rotman 1961. *Proc. Natl. Acad. Sci. USA* 47:1981-1991.

Useful chromophores include, for example, fluorescent, chemiluminescent, and bioluminescent molecules, as well as dyes. Some specific chromophores useful in the present invention include, for example, fluorescein, rhodamine, Texas red, phycoerythrin, umbelliferone, luminol.

Kits

The invention further includes a kit useful in the method for screening a human patient for a condition associated with undesired apoptosis. The kit comprises a probe, and at least one of the following: a label, buffers, standards containing proneurotrophin and its conjugates, materials for developing colorimetric labels, materials for stopping colorimetric reactions, etc.

GENERAL METHODS

The proteins of the present invention may be prepared by methods that are well known in the art. One such method includes isolating or synthesizing DNA encoding the pro-domains and/or mature domains of the proteins of the invention, and producing the recombinant protein by expressing the DNA, optionally in a recombinant vector, in a suitable host cell.

The proteins of the invention may also be made synthetically, i.e. from individual amino acids, or semisynthetically, i.e. from oligopeptide units or a combination of oligopeptide units and individual amino acids. Suitable methods for synthesizing proteins are described by Stuart and Young in "Solid Phase Peptide Synthesis," Second Edition, Pierce Chemical Company (1984), Solid Phase Peptide Synthesis, Methods Enzymol., 289, Academic Press, Inc, New York (1997) .

Nucleic acids encoding the proteins of the invention may also be synthesized *in vitro*. Suitable methods for synthesizing DNA are described by Caruthers et al. 1985. *Science* 230:281-285 and DNA Structure, Part A: Synthesis and Physical

Analysis of DNA, Lilley, D.M.J. and Dahlberg, J.E. (Eds.), Methods Enzymol., 211, Academic Press, Inc., New York (1992).

Nucleic acid molecules encoding the proneurotrophins of the invention may be designed or assembled from known nucleic acid sequences encoding neurotrophins or neurotrophin pro-domains or mature domains. The GenBank accession numbers for NGF, BDNF, NT-3, and NT-4/5 are M14805, M61176, M37763, and M86528, respectively. Alternatively, the nucleic acid sequence may be derived from a known proneurotrophin amino acid sequence using the genetic code, as is routine to those of skill in the art.

Databases and analytical software for the detection of proteins and nucleic acids having or encoding a particular sequence, pattern or motif are also readily available to the public, and provide useful protein or nucleic acid sequences for adaptation or modification for incorporation into the proneurotrophins of the present invention. For example the National Center for Biotechnology Information (NCBI) of the National Library of Medicine provides databases of protein and nucleic acid sequences and analytical and alignment software at <http://www.ncbi.nlm.nih.gov>.

The proteins of the invention may be isolated from soluble or membrane fractions of preparations, such as for example cell-free lysates, conditioned media or other biological samples containing them by standard methods of protein isolation and purification. Some suitable methods include precipitation and liquid/ chromatographic protocols such as for example, high performance liquid chromatography (HPLC), ion exchange, hydrophobic interaction chromatography, immunoprecipitation, lipid extraction, affinity chromatography and gel filtration to name but a few. See, for example, Guide to Protein Purification, Deutscher, M.P. (Ed.) Methods Enzymol., 182, Academic Press, Inc., New York (1990) and also Scopes, R.K. and Cantor, C.R. (Eds.), Protein Purification (3d), Springer-Verlag, New York (1994).

The methods, constructs and host cells suitable for production of desired proneurotrophin in standard small-scale culture systems, as well as large-scale production systems, include fermenter systems, hollow fiber culture systems, tumbler systems, and suspension culture systems to name but a few.

Methods and procedures for the manipulation of nucleic acids, polymerase chain reaction (PCR) methods for amplification of nucleic acids, construction of expression vectors, transformation of host cells, and the culture of transformed cells for the production of protein are known. These and many more relevant methods may be found in a variety of laboratory manuals, texts and guides. For a general guide, see, for instance, Sambrook & Russel, (2001) *Molecular Cloning*, Third edition, Cold Spring Harbor Press. Other useful sources include: Ausubel et al., 1992 *Short Protocols in Molecular Biology*, Second edition, John Wiley & Son; *Gene Expression Technology*, *Methods in Enzymology* Vol. 185 (ed. David Goeddel et al., Academic Press, Inc., London, 1991); *Gene Structure and Expression*, Second Edition, J. D. Hawkins (Cambridge University Press, London, 1991); *PCR Protocols: A Guide to Methods and Applications* (Innis, et al. 1990, Academic Press, San Diego, Calif.); *Methods in Molecular Biology* (Vol. 7), *Gene Transfer and Expression Protocols*, (ed. E. J. Murray, 1991, The Humana Press Inc., Clifton, N.J.).

Replication and Expression of Nucleic Acids Encoding Proteins of the Invention:

The nucleic acid encoding the proneurotrophins of the invention may be replicated and expressed in a suitable host cell. Suitable host cells include prokaryotic host cells and eukaryotic host cells. Suitable prokaryotic host cells include *E. coli* cells which are preferred. Suitable eukaryotic host cells include yeast cells, insect cells and mammalian cells, the latter being preferred.

Recombinant proneurotrophins are expressed in eukaryotic hosts in preference to prokaryotic hosts in cases where the protein must be post-transcriptionally modified. Examples of post-transcriptional modification include glycosylation,

phosphorylation, disulfide bond formation, oligomerization and specific cleavage of the transcribed protein product.

Prokaryotic hosts do not perform certain post-transcriptional modifications of proneurotrophins of the invention, such as for instance glycosylation. For this reason expression in eukaryotic systems is preferred despite the higher costs associated with production of biologics in eukaryotic systems as compared with the costs of biologics produced in prokaryotic host systems.

Prokaryotic host systems are preferred for expression and production of recombinant proneurotrophins of the invention that do not require post-transcriptional modifications that are unique to eukaryotic systems and where the recombinant proneurotrophins are correctly folded or may be refolded *in vitro*.

Many standard well known cloning and expression and isolation/purification techniques that reflect the state of the art in recombinant DNA and protein methods are described in detail in Sambrook & Russel, *Molecular Cloning: A Laboratory Manual*, Third Edition, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY (2001). Techniques for expression of cloned genes in *E. coli* and in mammalian cells is described in detail in Chapters 15 and 16-17, respectively of the Sambrook & Russel Laboratory Manual (Id).

Site directed mutagenesis of nucleic acids encoding the proneurotrophins:

One technique for preparing nucleic acid molecules encoding the proteins of the invention is site directed mutagenesis. Procedures and kits for performing site directed mutagenesis are known in the art. Basically, the nucleic acid sequence of a target sequence within the nucleic acid sequence encoding a native (naturally occurring) proneurotrophin, a chimeric or non-natural proneurotrophin or neurotrophin or fragment of any of the above, may be specifically targeted at will to yield either a random sequence or a predetermined sequence. The available methods for such site directed mutagenesis include chemical mutagenesis of isolated restriction

fragments encoding the target region or sequence, polymerase chain reaction (PCR) mediated mutagenesis of specific sequences and semisynthetic replacement of portions of a coding sequence. Several methods commonly used for site directed mutagenesis are described in detail in the Sambrook & Russel, A Laboratory Manual, at Chapter 13 (Id).

Antibodies

Methods for making monoclonal antibodies include, for example, the immunological method described by Kohler and Milstein 1975. *Nature* 256:495-497 and by Campbell in "Monoclonal Antibody Technology, The Production and Characterization of Rodent and Human Hybridomas" in Burdon, et al., Eds, Laboratory Techniques in Biochemistry and Molecular Biology, Volume 13, Elsevier Science Publishers, Amsterdam (1985). The recombinant DNA method described by Huse, et al. 1989 *Science* 246:1275-1281 is also suitable.

Briefly, in order to produce monoclonal antibodies, a host mammal is inoculated with an antigen, such as p75 receptor, a proneurotrophin protein, or a proneurotrophin protein-p75 receptor conjugate, as described above, and then, optionally, boosted. In order to be useful, the receptor fragment must contain sufficient amino acid residues to define the epitope of the molecule being detected. If the fragment is too short to be immunogenic, it may be conjugated to a carrier molecule. Some suitable carrier molecules include keyhole limpet hemocyanin and bovine serum albumin. Conjugation may be carried out by methods known in the art. One such method is to combine a cysteine residue of the fragment with a cysteine residue on the carrier molecule.

Spleens are collected from the inoculated mammals a few days after the final boost. Cell suspensions from the spleen are fused with a tumor cell. The resulting hybridoma cells that express the antibodies are isolated, grown and maintained in culture.

Suitable monoclonal antibodies as well as growth factor receptor tyrosine kinases for making them are also available from commercial sources, for example, from Upstate Biotechnology, Santa Cruz Biotechnology of Santa Cruz, California, Transduction Laboratories of Lexington, Kentucky, R&D Systems Inc of Minneapolis, Minnesota, and Dako Corporation of Carpinteria, California.

Methods for making chimeric and humanized antibodies are also known in the art. For example, methods for making chimeric antibodies include those described in U.S. patents by Boss (Celltech) and by Cabilly (Genentech). See U.S. Patent Nos. 4,816,397 and 4,816,567, respectively. Methods for making humanized antibodies are described, for example, in Winter, U.S. Patent No. 5,225,539.

Antibodies or antibody fragments can also be isolated from antibody phage libraries generated using techniques, for example, described in McCafferty et al. 1990. *Nature* 348: 552-554, using the antigen of interest to select for a suitable antibody or antibody fragment. Clackson et al. 1991. *Nature* 352: 624-628 and Marks et al. 1991. *J. Mol. Biol.* 222: 581-597 describe the isolation of murine and human antibodies, respectively, using phage libraries. Subsequent publications describe the production of high affinity (nM range) human antibodies by chain shuffling (Mark et al. 1992. *Bio/Technol.* 10: 779-783), as well as combinatorial infection and in vivo recombination as a strategy for constructing very large phage libraries (Waterhouse et al. 1993. *Nuc. Acids Res.* 21: 2265-2266). These techniques are viable alternatives to traditional monoclonal antibody hybridoma techniques for isolation of "monoclonal" antibodies (especially human antibodies).

The preferred method for the humanization of antibodies is called CDR-grafting. In CDR-grafting, the regions of a non-human mammalian antibodies, preferably a mouse antibody, that are directly involved in binding to antigen, the complementarity determining region or CDRs, are grafted into human variable regions to create "reshaped human" variable regions. These fully humanized variable regions are then joined to human constant regions to create complete "fully humanized" antibodies.

In order to create fully humanized antibodies that bind well to an antigen, it is advantageous to design the reshaped human variable regions carefully. The human variable regions into which the CDRs will be grafted should be carefully selected, and it is usually necessary to make a few amino acid changes at critical positions within the framework regions (FRs) of the human variable regions.

For example, the reshaped human variable regions may include up to ten amino acid changes in the FRs of the selected human light chain variable region, and as many as twelve amino acid changes in the FRs of the selected human heavy chain variable region. The DNA sequences coding for these reshaped human heavy and light chain variable region genes are joined to DNA sequences coding for the human heavy and light chain constant region genes, preferably $\gamma 1$ and κ , respectively. The reshaped humanized antibody is then expressed in mammalian cells and its affinity for its target compared with that of the corresponding murine antibody and chimeric antibody.

Methods for selecting the residues of the humanized antibody to be substituted and for making the substitutions are well known in the art. See, for example, Co et al. 1993. *Nature* 351:501-502; Queen et al., 1989. *Proc. Natl. Acad. Sci.* 86: 10029-1003 and Rodrigues et al. 1992. *Int. J. Cancer*, Supplement 7: 45-50. A method for humanizing and reshaping the 225 anti-EGFR monoclonal antibody described by Goldstein et al. in PCT application WO 96/40210. This method can be adapted to humanizing and reshaping antibodies against other growth factor receptor tyrosine kinases.

Methods for making single chain antibodies are also known in the art. Such methods include screening phage libraries transfected with immunoglobulin genes described in U.S. Patent 5,565,332; U.S. Patent 5,583,242; U.S. Patent 5,855,885; U.S. Patent 5,885,793; and U.S. Patent 5,969,108. Another method includes the use of a computer-based system for designing linker peptides for converting two separate

polypeptide chains into a single chain antibody described in U.S. Patent 4,946,778; U.S. Patent 5,260,203; U.S. Patent 5,455,030; and U.S. Patent 5,518,889.

Other methods for producing antibodies described above are disclosed by Wels et al. in European patent application EP 502 812 and *Int. J. Cancer* 60:137-144 (1995); PCT Application WO 93/21319; European Patent Application 239 400, PCT Application WO 89/09622; European Patent Application 338 745; U.S. Patent 5,658,570; U.S. Patent 5,693,780; and European Patent Application EP 332 424.

Labels

The labels may be conjugated to probes by methods that are well known in the art. The labels may be directly attached through a functional group on the probe. The probe either contains or can be caused to contain such a functional group. Some examples of suitable functional groups include, for example, amino, carboxyl, sulfhydryl, maleimide, isocyanate, isothiocyanate.

Alternatively, labels such as enzymes and chromophoric molecules may be conjugated to the antibodies or nucleotides by means of coupling agents, such as dialdehydes, carbodiimides, dimaleimides, and the like.

The label may also be conjugated to the probe by means of a ligand attached to the probe by a method described above and a receptor for that ligand attached to the label. Any of the known ligand-receptor combinations is suitable. Some suitable ligand-receptor pairs include, for example, biotin-avidin or -streptavidin, and antibody-antigen. The biotin-avidin combination is preferred.

The probe may be an antibody, preferably a monoclonal antibody. The antibodies may be prepared as described above.

Assays

The antibodies described above can be used in assays to detect the presence of the proteins, conjugates, and complexes. Such assays can be performed using known

formats such as immunohistochemistry/immunocytochemistry of tissues (U.S. Patent No. 5846749) and ELISA (Current Protocols in Immunology, Wiley Intersciences, New York, 1999).

Assays for detecting the presence of proteins with antibodies have been previously described, and follow known formats, such as standard blot and ELISA formats. These formats are normally based on incubating an antibody with a sample suspected of containing the protein and detecting the presence of a complex between the antibody and the protein. The antibody is labelled either before, during, or after the incubation step. The protein is preferably immobilized prior to detection. Immobilization may be accomplished by directly binding the protein to a solid surface, such as a microtiter well, or by binding the protein to immobilized antibodies.

In a preferred embodiment, a protein is immobilized on a solid support through an immobilized first antibody specific for the protein. The immobilized first antibody is incubated with a sample suspected of containing the protein. If present, the protein binds to the first antibody.

A second antibody, also specific for the protein, binds to the immobilized protein. The second antibody may be labelled by methods known in the art. Non-immobilized materials are washed away, and the presence of immobilized label indicates the presence of the protein. This and other immunoassays are described by David, et al. in U.S. Patent 4,376,110 assigned to Hybritech, Inc., La Jolla, California; by Coligan, J.E, et al. (Eds.), Current Protocols in Immunology, Wiley Intersciences, New York, 1999); and by Harlow, E. and Lane, D., Using Antibodies, A Laboratory Manual, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York (1999).

Immunoassays may involve one step or two steps. In a one-step assay, the target molecule, if it is present, is immobilized and incubated with a labelled antibody. The labelled antibody binds to the immobilized target molecule. After washing to remove unbound molecules, the sample is assayed for the presence of the label.

In a two-step assay, immobilized target molecule is incubated with an unlabelled first antibody. The target molecule-antibody complex, if present, is then bound to a second, labelled antibody that is specific for the unlabelled antibody. The sample is washed and assayed for the presence of the label, as described above.

The immunometric assays described above include simultaneous sandwich, forward sandwich, and reverse sandwich immunoassays. These terms are well known to those skilled in the art.

In each of the above immunoassays, the sample containing antigen, solid phase immunoabsorbent with immobilized antibody and labeled soluble antibody are incubated under conditions and for a period of time sufficient to allow antigen to bind to the immobilized antibodies and to the soluble antibodies. In general, it is desirable to provide incubation conditions sufficient to bind as much antigen as possible, since this maximizes the binding of labeled antibody to the solid phase, thereby increasing the signal. The specific concentrations of labeled and immobilized antibodies, the temperature and time of incubation, as well as other such assay conditions, can be varied, depending upon various factors including the concentration of antigen in the sample, the nature of the sample and the like. Those skilled in the art will be able to determine operative and optimal assay conditions for each determination by employing routine experimentation.

There are many solid phase immunoabsorbents which have been employed and which can be used in the present invention. Well known immunoabsorbents include beads formed from glass, polystyrene, polypropylene, dextran, nylon, and other material; and tubes formed from or coated with such materials, and the like. The immobilized antibodies may be covalently or physically bound to the solid phase immunoabsorbent, by techniques such as covalent bonding via an amide or ester linkage or by absorption.

EXAMPLES

The scope of the compositions and methods of the present invention may be better understood by those of skill in the art by reference to the following specific examples:

Example 1: Expression and isolation of His-tagged cleavage resistant NGF:

To assess the biological activity of proneurotrophins, NGF cDNAs were stably expressed in 293 cells, to generate microgram quantities of His-tagged native NGF, which is completely processed to the mature form of 13.5 kDa in 293 media and a His-tagged point mutant of pro-NGF, in which the K-R cleavage site at 120,121 has been mutated to A-A. This renders the molecule cleavage resistant, and results in a proform of NGF of 30 kDa isolated from 293 cell media (Fig. 6).

Example 2. Identification of proteases for cleavage of a neurotrophin, NGF, to its mature form:

To determine if plasmin, MMP-3, MMP-7 or MMP-9 can cleave secreted pro-NGF, purified proNGF was incubated with the proteinases with or without inhibitors. Pro-NGF was cleaved by plasmin to a 13 kD form. Inhibition of plasmin activity upon addition of aprotinin inhibited cleavage of pro-NGF. In addition, incubation of the pro-NGF with MMP-7 but not MMP-2, -3, or -9 resulted in cleavage of the 30 kD proform of NGF to the 17 kD form (Fig. 7).

Example 3: Assays of the biological activity of cleavage resistant NGF:

These proteins have been highly purified and utilized in (1) binding assays, (2) apoptosis assays using cells expressing only p75 and (3) assays of trk activity, using trk-mediated autophosphorylation in dose-response studies and PC12 cell neuritogenesis.

The cleavage resistant proform of NGF binds with higher affinity than the cleaved mature form of NGF to the p75 receptor. Competition binding assays were performed to determine the affinity of interaction of the uncleaved proform to p75 or to trk A. Commercially purchased, predominantly mature NGF (Enzo Products for Science, Farmingdale, NY) was radiolabeled and incubated with cells expressing only p75, in the presence or absence of increasing concentrations of either unlabeled cleaved NGF, or of unlabeled cleavage resistant pro-NGF. As shown in Fig. 8A, the IC_{50} of cleaved NGF is 1.0nM, consistent with prior reports. However, the IC_{50} of the uncleaved proform is 0.2nM, indicating that the uncleaved proform is approximately 5 times as effective in binding p75 as is cleaved NGF. In contrast, competition curves generated using 293 cells expressing only trk A (Fig. 8B), demonstrate that the IC_{50} of mature NGF is 1.2nM, and the cleavage resistant pro-NGF is greater than 5nM. Thus, the cleavage resistant pro-NGF proform binds less effectively to trk A.

Example 4: The cleavage resistant pro-NGF is more effective than mature NGF in inducing apoptosis of cells expressing only p75:

To determine if the enhanced binding of cleavage resistant pro-NGF to p75 resulted in increased p75-mediated apoptosis, a vascular smooth muscle cell line expressing p75 (but not trk receptors) which exhibits dose dependent apoptosis upon NGF addition was used in the following experiments. Cells were exposed to His tagged mature NGF or His tagged uncleaved NGF purified from 293 cell media (see Fig. 6) or as controls, purified media from cells transfected with vector or commercial (predominantly mature) NGF. Apoptosis was assessed by TUNEL analysis at 18h post-treatment (See Fig. 9A). Less than 5% of the control cells were TUNEL-positive. Commercial, mature NGF induced 20% TUNEL positive cells at 2 nM, consistent with prior reports, and purified media from vector transfected cells did not induce TUNEL positivity. Mature His-tagged NGF appeared similar to commercial NGF in inducing TUNEL positivity whereas the cleavage resistant pro-NGF was at least 10 times as effective in inducing apoptosis, with 18% TUNEL positive cells following treatment with 0.1 nM cleavage resistant pro-NGF. This result is in good

agreement with the binding data (Fig. 8A), and indicates that occupancy of only 30% of the p75 receptors with uncleaved NGF can initiate apoptosis.

Example 5. The cleavage resistant pro-NGF is less effective in activating trk:

To determine the relative activities of mature NGF and cleavage resistant pro-NGF in activating trk-mediated cellular responses, the autophosphorylation of trk A in dose-response studies was examined. Mature NGF and commercial NGF induced trk A autophosphorylation at a concentration of 0.2 nM. However, cleavage resistant pro-NGF did not induce trk A phosphorylation even at concentrations of 1 nM. This result is in good agreement with the observed reduction in trkA binding (see Fig. 8A).

Example 6: The cleavage resistant pro-NGF is less effective than mature NGF in mediating trk dependent neuritogenesis:

To determine the relative activities of uncleaved and cleaved NGF in activating trk receptors, PC12 cells were utilized in neuritogenesis assays (Fig. 9B). Treatment of these cells with His-tagged mature, or commercial (predominantly mature) NGF, induced neurites at 0.1 nM concentrations. However, no neurite outgrowth was observed in cells that were treated with the cleavage resistant pro-NGF even at concentrations up to 2 nM. PC12 cells treated with purified media from cells transfected with vector displayed no neurite outgrowth. As a control, TUNEL analysis was performed on replicate cultures; less than 2% cell death were observed under all conditions tested.

Example 7. Pro-NGF induces cell death in neurons coexpressing p75 and trk A:

Superior cervical ganglia neurons coexpress both p75 and trk A receptors. The neurons were treated with either mature NGF or pro-NGF. Treatment of superior cervical ganglia neurons with pro-NGF resulted in cell death (Fig. 9D). Treatment with mature NGF resulted in very little cell death (Fig. 9C).

Example 8: Expression of BDNF in eukaryotic cells:

Recombinant adenovirus may be utilized to express rat BDNF in 293T cells, or endothelial cells, an in vivo source of BDNF in the CNS and extraneuronal sites (Donovan, M. J., et al. 2000. Development 127:4531-4540; Leventhal, C., et al. 1999. Mol. Cell. Neurosci. 13:450-464). Forty-eight hours following cell infection, BDNF released into the culture media is detected by Western blot using an antibody specific for epitopes in the mature BDNF protein. Immunoreactive proteins of 30 kDa, 28 kDa, 24 kDa and 14 kDa are secreted into the media of 293 cells (Fig. 10A), and products of 28 kDa and 14 kDa are detectable from media of endothelial cells (Fig. 10B). Approximately 1.1 microgram/ml /24h is secreted by infected cells, as determined by ELISA analysis, using recombinant BDNF as a standard.

Example 9: Identification of proteases that are essential for the cleavage of a neurotrophin, BDNF, to its mature form:

To determine if plasmin, MMP-3 or MMP-7 can cleave secreted BDNF, recombinant proteases were added to the media from adenoviral infected cells, and all these enzymes led to a reduction in the proforms of 30 kDa in 293 cells while MMP-2 was without effect (Fig. 10A). In endothelial media, only plasmin and MMP-7 appeared to cleave the large proform (Fig. 10B), perhaps reflecting differences in TIMP by endothelial cells as compared to 293 cells. Treatment of the media with recombinant MMP7 resulted in a reduction in the high molecular weight isoforms of 30 kDa or 28kDa, and the generation of a novel form of approximately 17 kDa. The specificity of proteolysis by plasmin was confirmed by concomitant incubation with its inhibitor aprotinin, or the inclusion of an MMP-7 inhibitory peptide, which in each case inhibited the cleavage of a proform of BDNF.

To confirm that cleavage of proforms to mature BDNF occurs extracellularly, adenovirally infected cultures were incubated with plasmin, or a combination of plasmin plus aprotinin in the media for 48 hours prior to media collection. As shown in Fig. 10C, inhibition of plasmin activity upon addition of aprotinin reduced the

cleavage of high molecular weight forms of BDNF, strongly suggesting that these higher molecular weight proforms are released from cells, and that plasmin cleavage occurs on the surface of intact cells.

Recombinant native murine NGF, as well as NGF with the R-R (-1, 0) mutant to A-A constructs have been prepared. Because the NGF start site does not conform to a Kozak consensus sequence, impairing efficient translation, the 15 bases upstream of the NGF ATG (-14 to 0) was substituted for (-14 to 0) of the NT-3 sequence, yielding a cDNA which utilizes the NT-3 Kozak site and the entire NGF coding sequence. With this construct, secreted NGF from transiently transfected 293 cells are obtained at significant levels (0.5 micrograms/100 mm² plate/24 hr.). The dibasic site (R-R) at (-1, 0) is mutated to A-A using a PCR based Quik-Change method, and likewise the dibasic site at the carboxyl-terminus (+118,+119) is mutated to prevent cleavage of the His tag. Mutated cDNAs are subjected to complete bidirectional sequencing, and subcloned into the pcDNA expression vector.

Both native His-tagged NGF and the (R-R) to (A-A) mutant have been isolated from the media of transiently transfected 293 cells using a Ni-Sepharose column. The His-tagged NGF, migrating at 14 kDa, displays no loss of biological activity as compared to commercial recombinant NGF, as assessed in PC12 neurite outgrowth assays. These results suggest that the C-terminal His-tag does not impair NGF binding to trk A, and is consistent with the crystallographic structure of the NGF/trk A complex, in which the C-terminal tail of NGF is not involved in NGF/trk A interfaces.

Example 10: Binding studies with cleavage resistant neurotrophins:

Binding of cleavage resistant neurotrophins may be compared to native, mature NGF or BDNF to either p75, or their cognate trk receptors, using competition displacement studies.

The methodology for these studies is well described in recent publications (Rydén, M., et al. 1997. *The Journal of Biological Chemistry* **272**:16322-16328). In brief, mature-His tagged or cleavage resistant-His tagged neurotrophin is radioiodinated to a specific activity of approximately 2800dpm/fmole. Iodinations using 0.5 µg of neurotrophin routinely generate material for approximately 20 binding studies (Hempstead, B. L., et al. 1991. *Nature* **350**:678-683). For competition analysis, 3T3 cells stably expressing trk A or trk B, or 3T3 cells stably expressing p75 (lines with 75,000 receptors/cell are available, see for example Mahadeo, D., et al. 1994 *J. Biol. Chem.* **269**:6884-91) are incubated concomitantly with radioiodinated neurotrophin (at 10^{-9} M) and unlabeled native neurotrophin at increasing concentrations (10^{-10} to 10^{-8} M) at 4°C for 2 hours. Bound ligand is separated from free by centrifugation of cells as described (Ryden M., et al., *EMBO J.* **14**: 1979-90) and the binding properties of each mutant neurotrophin is determined by calculating the IC₅₀ (the concentration of inhibitor which reduces binding by 50%).

Example 11. Tissue Expression of Neurotrophins:

To determine the tissue expression of neurotrophins, adult mouse tissues were probed with antibodies that recognize the mature region of NGF or BDNF. In adult tissues, both mature (approximately 14 kD) and larger preproisoforms of both NGF and BDNF were detected (Fig. 11A and B). The larger isoforms of NGF were also present in the commercial preparations of recombinant NGF. In the tissue extracts from adult mice, the detectable neurotrophin proteins ranged in size from 14 kD (mature form) to approximately 30 kD (size of the unprocessed, preproform). Intermediately sized proteins of 16, 18, and 22 kD for NGF and 18, 22, 28, and 30 kD for BDNF were also detected. The data demonstrates that proforms of NGF and BDNF are expressed at significant levels in many adult tissues. In addition, the data shows that tissues process NGF and BDNF differently.

Example 12. Antibodies specific to the pro-domain of pro-BDNF and pro-NGF:

The antibodies available to date have been generated to the mature domain of the neurotrophins, thus recognizing both mature and pro-forms. To develop specific antibodies that are specific for the pro-domain of BDNF and NGF, and that can distinguish pro- from mature forms of BDNF and NGF, GST-fusion proteins encoding amino acids 20-80 of BDNF or amino acids 20-82 of NGF were generated and used as immunogens in chickens (for BDNF) or rabbits (for NGF). The antisera was affinity purified using columns of the immunogen. The antisera to pro-NGF detects pro-NGF, but not mature NGF (Fig. 12A). The antisera to pro-BDNF detects pro-BDNF, but not mature BDNF (Fig. 12B).

Example 13. Pro-BDNF and pro-NGF are expressed in lesions of vascular injury:

The expression and localization of the pro-forms and mature forms of NGF and BDNF in murine models of vascular injury was assessed. In lesions from Western-diet fed ApoE (-/-) animals, both the pro- and mature NGF were more highly expressed in the plaque, as compared to the medial smooth muscle cell layer. A similar pattern was detected with BDNF antisera. Both the pro- and mature BDNF immunoreactivity were preferentially expressed in the lesions, as compared to the media, with further restriction of the pro-BDNF immunoreactivity to the cellular area near the vessel lumen. Mature, but not pro-BDNF is expressed by endothelial cells in uninjured, normal adventitial vessels.

Example 14. Expression of pro- and mature NGF and BDNF in human atherosclerotic lesions:

To assess the expression of NGF and BDNF isoforms in human atherosclerotic lesions, advanced plaques obtained at endarterectomy of symptomatic carotid lesions were microscopically dissected. Tissues from the media, the necrotic core, or the fibrous cap were subjected to detergent solubilization. In parallel, tissue consisting of all three regions was solubilized without dissection. Immunoreactive bands at approximately 26 kD were detected in extracts from human atherosclerotic

lesions when probed with antisera to the mature (Fig. 13A) or pro-domain specific BDNF (Fig. 13B). The molecular size, and immunoreactivity with pro-domain specific antisera is consistent with pro-BDNF. Similarly, Western blot analysis using mature NGF (Fig. 13C) and pro-BDNF (Fig. 13D) antisera detected a 26-28 kd species, which is consistent with pro-BDNF.

Example 15: Construction of a replication deficient recombinant adenovirus based on human serotype 5:

Neurotrophin cDNA is subcloned in the shuttle vector (p.shuttle.cmv) and cotransformed with pAdEasy (containing the adenovirus serotype 5 genome with deletions in E1-E3 regions) in bacteria. Homologous recombination replaces the E1 region of pAdEasy with the mutant neurotrophin cDNA and plasmids are isolated and screened for neurotrophin cDNA expression by PCR. Recombinant plasmid is transfected into 293 cells and viral particles are plaque purified. High titer stocks are prepared, using cesium chloride ultracentrifugation, and the viral concentration determined by plaque titration. Viral stocks are used to infect 293 cells at a MOI of 10 for 90 min, and neurotrophins purified from the media 2 days after infection using Ni chromatography as outlined above. Purity is assessed by silver stain; if additional purification is necessary to obtain preparations which are >95% pure, reverse phase chromatography is performed (Ryden, M., et al. 1995. EMBO J 14:1979-90).

Equilibrium binding studies are performed using the radioiodinated cleavage resistant mutant neurotrophin, with or without excess unlabeled mutant neurotrophin to assess specific binding (see Hempstead, B. L., et al. 1991. Nature 350:678-683. and Mahadeo, D., et al. 1994. J. Biol. Chem. 269:6884-91 for detailed methods). In brief, samples of increasing concentrations (10^{-11} to 10^{-8} M) of the radioiodinated ligand is incubated with a constant number of 3T3 cells expressing either p75 or trk, at 4 °C for 2 hours. Bound ligand is separated from free by cell centrifugation, and pellets counted for associated radioactivity. Specific binding is generally greater than 75% of total binding. Scatchard plot analysis allows calculations of the affinity of interaction (K_D), as well as assessment of a single or multiple affinity binding sites.

Example 16: Receptor Activation by Neurotrophin Mutants:

Trk activation is assessed in 3T3 cells expressing either trk A, trk B or trk C. For a dose response analysis, cells are treated with mature or cleavage resistant neurotrophins (10^{-10} to 10^{-8} M). The rapid trk autophosphorylation (within 5 min), and phosphorylation and activation of well defined downstream signaling events such as MAP kinase and PI-3 kinase may be assessed by standard methods. From cells lysed in detergent buffer containing phosphatase and protease inhibitors, trk, or MAP kinase are immunoprecipitated and Western blotted using anti-PY antisera. MAP and PI-3 kinase kinase activation is quantified using immunoprecipitation (IP)-kinase assays, as has been described (Hempstead, B. L., et al. 1992. *Neuron* 9:883-896). The dose response analysis of ligand binding to trk may then be compared with the induction of trk activation.

Parallel studies may be performed with cells expressing only p75 receptors. The quantitative assessment of p75 receptor activation is not as straightforward, as many of the downstream signaling cascades activated by p75 require that the cells are concomitantly stressed (JNK activation, and NF κ B activation) or elicit only modest enhancements (ceramide production) following neurotrophin addition (reviewed in Casaccia-Bonnel, P., et al. 1999: "The Functional Roles of Glial Cells in Health and Disease." Plenum, New York. However, ligand induced p75-TRAF6 interaction is suitable for quantitative analysis. See Khursigara, G., et al. 1999. *J Biol Chem* 274:2597-600.

293 cells transiently expressing p75 and TRAF6 may be used for dose-response analysis, by incubating cells with mature or cleavage resistant neurotrophin (10^{-10} to 10^{-8} M) for 5 minutes. Cells are then lysed, and a co-immunoprecipitation analysis of p75:TRAF6 complexes performed by immunoprecipitating with anti-p75 and probing for FLAG-tagged TRAF6. Based on prior studies (Kursigawa and Chao, 1999), the neurotrophins must be present at concentrations of 4 nM or greater to induce complex formation between p75 and TRAF6. Cleavage resistant

neurotrophins which have enhanced binding affinity for p75 may be identified in this way.

Cleavage resistant mutants may also be characterized for binding and activation of p75 and trks independently and in cells which co-express both receptors. Using available 293 cell lines and PC12 cell lines which co-express either trk A/p75 or trk B/p75 at approximately 75,000 trk and 75,000 p75 receptors per cell, the dose responsiveness of these cells to mature and cleavage resistant neurotrophins may be determined using trk autophosphorylation, MAP kinase activation and PI-3 kinase activation as trk signaling predominates when both receptors are expressed (Casaccia-Bonofil, P., et al. 1999. *The Functional Roles of Glial Cells in Health and Disease*. Plenum, New York).

Example 17: Biological effects of cleavage resistant neurotrophins:

To assess the relative potency of native and cleavage resistant neurotrophins to activate trk receptors, trk A or trk B expressing fibroblasts are used in cell proliferation analysis. These assays do not require p75 expression, and are highly quantitative (See Arevalo, J. C., et al. 2000. *Mol Cell Biol* 20:5908-16), thus allowing activation by native neurotrophins to be distinguished from those mutants which may exhibit reduced activity. In brief, cells cultured in serum free media are treated with or without increasing concentrations of native or cleavage resistant neurotrophins for 24 hr, then pulsed with ³H-thymidine. Thymidine incorporation, as a measurement of cell proliferation, is quantitated in a filter binding assay (Arevalo, J. C., id.). The cleavage resistant neurotrophins exhibit reduced proliferation when they are impaired in trk binding.

To assess p75 activation, two model systems are utilized in which native neurotrophins initiate an apoptotic response:

The first model is neurotrophin induced apoptosis of p75 expressing vascular smooth muscle cells (Wang, S., et al. 2000. *Am J Pathol* 157:1247-1258) which

exhibit dose dependent increases in apoptosis using 2-5 nM NGF or BDNF, as quantitated by flow cytometric analysis of Annexin V binding. Concentrations of neurotrophin below 2 nM are not effective whereas dose responsiveness at 2-5nM concentrations provides a quantitative analysis necessary to distinguish between ligands with reduced or enhanced activation of p75. p75 expressing vascular smooth muscle cells are treated with native or cleavage resistant neurotrophins for 18 hrs, and the proportion of cells exhibiting early or late apoptosis quantitated using flow cytometric analysis. Cells with Annexin V binding, but no propidium iodide uptake (early apoptosis) or both Annexin V binding and propidium iodide uptake (indicative of late apoptosis) are quantitated readily, as has been detailed (Wang, S., et al. 2000. *Am J Pathol* **157**:1247-1258).

In addition, the rat neonatal oligodendrocyte assay, may be used (Casaccia-Bonofil, P., et al. 1996. *Nature* **383**:716-719). Cell cultured in oligodendrocyte differentiation media is switched to serum free media on neurotrophins (0.5 to 10 nM) and cell apoptosis is quantitated by TUNEL analysis at 8 hours.

Lastly, neuronal cultures may be used to compare the biological actions of native or cleavage resistant neurotrophins on cells which express both trk and p75, and exhibit responsiveness by neuritogenesis and survival. Primary cell cultures may be used, for example, cervical ganglion neurons, hippocampal neurons or dorsal root ganglion neurons. In addition, stable PC12 cell clones expressing either trk A or trk B at significant levels (approximately 70,000 receptors/cell) and have well characterized responses in terms of neurite extension (Hempstead, B. L., et al. 1992. *Neuron* **9**:883-896) are preferred. Dose response studies (0.5×10^{-11} M) are performed using native or cleavage resistant proneurotrophin and neurite outgrowth at 48 hours is quantitated by counting cells with neurites of greater than two cell bodies in length. Cell survival assays may be performed, using neurons from rat dorsal root ganglia. These cells express either trk A and p75, or trk B and p75, and thus are useful in assessing the biological activities of mutant NGF or BDNF.

Results obtained using cells which co-express both p75 and trk receptors are interpreted in the context of those obtained using cells which express each receptor independently, as well as in the results of receptor binding studies. This careful analysis of biological activity, in conjunction with assessment of affinity constants and association and dissociation constants, allows clear identifications of the actions of larger proforms of the neurotrophins to (1) selectively bind p75 or trk receptors independently; (2) bind to high affinity multimeric receptor complexes and (3) distinguish between apoptotic and differentiation/survival activities in neurons and oligodendrocytes.

Taken together, these results indicate that the uncleaved, pro-form of neurotrophins is a preferred ligand for the pro-apoptotic p75 receptor, whereas the proteolytically cleaved mature neurotrophins is the preferred ligand for trk receptors. These results indicate that the regulated cleavage of proneurotrophins profoundly alters their biological actions, and that the proneurotrophins are higher affinity ligands for p75.

What is claimed is:

1. An isolated protein comprising a pro-domain of a proneurotrophin, the pro-domain comprising a pro-domain conserved region, the conserved region being an amino acid sequence having at least approximately 85% identity to amino acid residues approximately at positions 79-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3, or 43-57 of human NT-4/5.
2. A protein according to claim 1, wherein the conserved region is an amino acid sequence having at least approximately 90% identity to amino acid residues approximately at positions 79-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3; or 43-57 of human NT-4/5.
3. A protein according to claim 1, wherein the conserved region is an amino acid sequence having at least approximately 95% identity to amino acid residues approximately at position 79-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3; or 43-57 of human NT-4/5.
4. A protein according to claim 1, wherein the conserved region is an amino acid sequence having amino acid residues approximately at positions 79-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3; or 43-57 of human NT-4/5.
5. A protein according to claim 1, wherein the pro-domain further comprises an amino acid sequence having at least approximately 85% identity to amino acid residues approximately at positions 99-117 of human NGF; 106-124 of human BDNF; 116-134 of human NT-3; or 58-76 of human NT-4/5.
6. A protein according to claim 2, wherein the pro-domain further comprises an amino acid sequence having at least approximately 90% identity to amino acid residues approximately at positions 99-117 of human NGF; 106-124 of human BDNF; 116-134 of human NT-3; or 58-76 of human NT-4/5.

7. A protein according to claim 3, wherein the pro-domain further comprises an amino acid sequence having at least approximately 95% identity to amino acid residues approximately at positions 99-117 of human NGF; 106-124 of human BDNF; 116-134 of human NT-3; or 58-76 of human NT-4/5.
8. A protein according to claim 4, wherein the pro-domain further comprises an amino acid sequence having amino acid residues approximately at positions 99-117 of human NGF; 106-124 of human BDNF; 116-134 of human NT-3; or 58-76 of human NT-4/5.
9. A protein according to claim 1, wherein the pro-domain further comprises an amino acid sequence having at least approximately 85% identity to amino acid residues approximately at positions 66-78 of human NGF; 73-90 of human BDNF; 83-100 of human NT-3; or 25-42 of human NT-4/5.
10. A protein according to claim 2, wherein the pro-domain further comprises an amino acid sequence having at least approximately 90% identity to amino acid residues approximately at positions 66-78 of human NGF; 73-90 of human BDNF; 83-100 of human NT-3; or 25-42 of human NT-4/5.
11. A protein according to claim 3, wherein the pro-domain further comprises an amino acid sequence having at least approximately 95% identity to amino acid residues approximately at positions 66-78 of human NGF; 73-90 of human BDNF; 83-100 of human NT-3; or 25-42 of human NT-4/5.
12. A protein according to claim 4, wherein the pro-domain further comprises an amino acid sequence having amino acid residues approximately at positions 66-78 of human NGF; 73-90 of human BDNF; 83-100 of human NT-3; or 25-42 of human NT-4/5.
13. A protein according to claim 9, wherein the pro-domain further comprises an amino acid sequence having at least approximately 85% identity to amino acid

residues approximately at positions 46-65 of human NGF; 57-72 of human BDNF; or 61-82 of human NT-3.

14. A protein according to claim 10, wherein the pro-domain further comprises an amino acid sequence having at least approximately 90% identity to amino acid residues approximately at positions 46-65 of human NGF; 57-72 of human BDNF; or 61-82 of human NT-3.

15. A protein according to claim 11, wherein the pro-domain further comprises an amino acid sequence having at least approximately 95% identity to amino acid residues approximately at positions 46-65 of human NGF; 57-72 of human BDNF; or 61-82 of human NT-3.

16. A protein according to claim 12, wherein the pro-domain further comprises an amino acid sequence having amino acid residues approximately at positions 46-65 of human NGF; 57-72 of human BDNF; or 61-82 of human NT-3.

17. A protein according to claim 1, wherein the pro-domain further comprises an amino acid sequence having at least approximately 85% identity to amino acid residues approximately at positions 46-117 of human NGF; 57-124 of human BDNF; 61-134 of human NT-3; or 25-76 of human NT-4/5.

18. A protein according to claim 2, wherein the pro-domain further comprises an amino acid sequence having at least approximately 90% identity to amino acid residues approximately at positions 46-117 of human NGF; 57-124 of human BDNF; 61-134 of human NT-3; or 25-76 of human NT-4/5.

19. A protein according to claim 3, wherein the pro-domain further comprises an amino acid sequence having at least approximately 95% identity to amino acid residues approximately at positions 46-117 of human NGF; 57-124 of human BDNF; 61-134 of human NT-3; or 25-76 of human NT-4/5.

20. A protein according to claim 4, wherein the pro-domain further comprises an amino acid sequence having amino acid residues approximately at positions 46-117 of human NGF; 57-124 of human BDNF; 61-134 of human NT-3; or 25-76 of human NT-4/5.

21. A protein according to claim 1, wherein the pro-domain comprises an amino acid sequence having amino acid residues approximately at positions: 1-117, 19-117, 51-117, 81-117, or 82-117 of the human pro-domain of NGF; 1-124, 19-124, 58-124, 110-124, 111-124, or 113-124 of the human pro-domain of BDNF; 1-134, 19-134, or 99-134 of the human pro-domain of NT-3; or 1-76, 25-76, 62-76, or 63-76 of the human pro-domain of NT-4/5.

22. A protein according to claim 1, wherein the protein lacks a mature neurotrophin domain.

23. A protein according to claim 1, wherein the protein is purified.

24. A pharmaceutical composition that comprises a protein and a pharmaceutically acceptable additive, the protein comprising: a pro-domain of a proneurotrophin, the pro-domain comprising a pro-domain conserved region, the conserved region being an amino acid sequence having at least approximately 85% identity to amino acid residues approximately at positions 84-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3, or 43-57 of human NT-4/5.

25. A pharmaceutical composition according to claim 24, wherein the conserved region is an amino acid sequence having at least approximately 90% identity to amino acid residues approximately at positions 84-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3; or 43-57 of human NT-4/5.

26. A pharmaceutical composition according to claim 24, wherein the conserved region is an amino acid sequence having at least approximately 95% identity to amino

acid residues approximately at positions 84-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3; or 43-57 of human NT-4/5.

27. A pharmaceutical composition according to claim 24, wherein the conserved region is an amino acid sequence having amino acid residues approximately at positions 84-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3, or 43-57 of human NT-4/5.

28. A pharmaceutical composition according to claim 24, wherein the pro-domain further comprises an amino acid sequence having at least approximately 85% identity to amino acid residues approximately at positions 99-117 of human NGF; 106-124 of human BDNF; 116-134 of human NT-3; or 58-76 of human NT-4/5.

29. A pharmaceutical composition according to claim 25, wherein the pro-domain further comprises an amino acid sequence having at least approximately 90% identity to amino acid residues approximately at positions 99-117 of human NGF; 106-124 of human BDNF; 116-134 of human NT-3; or 58-76 of human NT-4/5.

30. A pharmaceutical composition according to claim 26, wherein the pro-domain further comprises an amino acid sequence having at least approximately 95% identity to amino acid residues approximately at positions 99-117 of human NGF; 106-124 of human BDNF; 116-134 of human NT-3; or 58-76 of human NT-4/5.

31. A pharmaceutical composition according to claim 27, wherein the pro-domain further comprises an amino acid sequence having amino acid residues approximately at positions 99-117 of human NGF; 106-124 of human BDNF; 116-134 of human NT-3; or 58-76 of human NT-4/5.

32. A pharmaceutical composition according to claim 24, wherein the pro-domain further comprises an amino acid sequence having at least approximately 85% identity to amino acid residues approximately at positions 66-83 of human NGF; 73-90 of human BDNF; 83-100 of human NT-3; or 25-42 of human NT-4/5.

33. A pharmaceutical composition according to claim 25, wherein the pro-domain further comprises an amino acid sequence having at least approximately 90% identity to amino acid residues approximately at positions 66-83 of human NGF; 73-90 of human BDNF; 83-100 of human NT-3; or 25-42 of human NT-4/5.
34. A pharmaceutical composition according to claim 26, wherein the pro-domain further comprises an amino acid sequence having at least approximately 95% identity to amino acid residues approximately at positions 66-83 of human NGF; 73-90 of human BDNF; 83-100 of human NT-3; or 25-42 of human NT-4/5.
35. A pharmaceutical composition according to claim 27, wherein the pro-domain further comprises an amino acid sequence having amino acid residues approximately at positions 66-83 of human NGF; 73-90 of human BDNF; 83-100 of human NT-3; or 25-42 of human NT-4/5.
36. A pharmaceutical composition according to claim 32, wherein the pro-domain further comprises an amino acid sequence having at least approximately 85% identity to amino acid residues approximately at positions 46-65 of human NGF; 57-72 of human BDNF; or 61-82 of human NT-3.
37. A pharmaceutical composition according to claim 33, wherein the pro-domain further comprises an amino acid sequence having at least approximately 90% identity to amino acid residues approximately at positions 46-65 of human NGF; 57-72 of human BDNF; or 61-82 of human NT-3.
38. A pharmaceutical composition according to claim 34, wherein the pro-domain further comprises an amino acid sequence having at least approximately 95% identity to amino acid residues approximately at positions 46-65 of human NGF; 57-72 of human BDNF; or 61-82 of human NT-3.

39. A pharmaceutical composition according to claim 35, wherein the pro-domain further comprises an amino acid sequence having amino acid residues approximately at positions 46-65 of human NGF; 57-72 of human BDNF; or 61-82 of human NT-3.

40. A pharmaceutical composition according to claim 24, wherein the pro-domain further comprises an amino acid sequence having at least approximately 85% identity to amino acid residues approximately at positions 46-117 of human NGF; 57-124 of human BDNF; 61-134 of human NT-3; or 25-76 of human NT-4/5.

41. A pharmaceutical composition according to claim 25, wherein the pro-domain further comprises an amino acid sequence having at least approximately 90% identity to amino acid residues approximately at positions 46-117 of human NGF; 57-124 of human BDNF; 61-134 of human NT-3; or 25-76 of human NT-4/5.

42. A pharmaceutical composition according to claim 26, wherein the pro-domain further comprises an amino acid sequence having at least approximately 95% identity to amino acid residues approximately at positions 46-117 of human NGF; 57-124 of human BDNF; 61-134 of human NT-3; or 25-76 of human NT-4/5.

43. A pharmaceutical composition according to claim 27, wherein the pro-domain further comprises an amino acid sequence having amino acid residues approximately at positions 46-117 of human NGF; 57-124 of human BDNF; 61-134 of human NT-3; or 25-76 of human NT-4/5.

44. A pharmaceutical composition according to claim 24, wherein the pro-domain comprises an amino acid sequence having amino acid residues approximately at positions: 1-117, 19-117, 51-117, 81-117, or 82-117 of the human pro-domain of NGF; 1-124, 19-124, 58-124, 110-124, 111-124, or 113-124 of the human pro-domain of BDNF; 1-134, 19-134, or 99-134 of the human pro-domain of NT-3; or 1-76, 25-76, 62-76, or 63-76 of the human pro-domain of NT-4/5.

45. A pharmaceutical composition according to claim 24.

46. An isolated protein comprising: (i) a pro-domain of a proneurotrophin, the pro-domain comprising a pro-domain conserved region; (ii) a mature neurotrophin domain; and (iii) a connector that joins the pro-domain conserved region to the mature neurotrophin domain and that is resistant to protease cleavage.

47. A protein according to claim 46, wherein the pro-domain comprises a pro-domain conserved region, the conserved region being an amino acid sequence having at least approximately 85% identity to amino acid residues approximately at positions 84-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3, or 43-57 of human NT-4/5.

48. A protein according to claim 46, wherein the conserved region is an amino acid sequence having at least approximately 90% identity to amino acid residues approximately at positions 84-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3; or 43-57 of human NT-4/5.

49. A protein according to claim 46, wherein the conserved region is an amino acid sequence having at least approximately 95% identity to amino acid residues approximately at positions 84-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3; or 43-57 of human NT-4/5.

50. A protein according to claim 46, wherein the conserved region is an amino acid sequence having amino acid residues approximately at positions 84-98 of human NGF; 91-105 of human BDNF; 101-115 of human NT-3, or 43-57 of human NT-4/5.

51. A protein according to claim 46, wherein the pro-domain comprises an amino acid sequence having amino acid residues approximately at positions: 1-117, 19-117, 51-117, 81-117, or 82-117 of the human pro-domain of NGF; 1-124, 19-124, 58-124, 110-124, 111-124, or 113-124 of the human pro-domain of BDNF; 1-134, 19-134, or 99-134 of the human pro-domain of NT-3; or 1-76, 25-76, 62-76, or 63-76 of the human pro-domain of NT-4/5.

52. A protein according to claim 46, wherein the sequence of the pro-domain is the sequence of a human pro-domain.
53. A protein according to claim 46, wherein the sequence of the mature neurotrophin domain is the sequence of a human mature neurotrophin domain.
54. A protein according to claim 46, wherein the sequence of the pro-domain and the sequence of the mature neurotrophin domain are found in the same native proneurotrophin protein.
55. A protein according to claim 46, wherein the sequence of the pro-domain and the sequence of the mature neurotrophin domain are not found in the same native proneurotrophin protein.
56. A protein according to claim 46, wherein the connector comprises four amino acids.
57. A protein according to claim 46, wherein the connector comprises one to three amino acids.
58. A protein according to claim 46, wherein the connector consists of a peptide bond.
59. A protein according to claim 46, wherein the connector comprises A-A.
60. A protein according to claim 59, wherein the connector comprises R-S-A-A.
61. A protein according to claim 59, wherein the connector comprises R-V-A-A.
62. A protein according to claim 59, wherein the connector comprises R-A-A-A.
63. A protein according to claim 59, wherein the connector comprises A-A-A-A.

64. A protein according to claim 46, wherein the cleavage site E-X-S/A found in native proneurotrophin proteins starting at approximately position 9 to approximately position 13 in the mature neurotrophin domain is not present, and its replacement, if any, is protease cleavage resistant.
65. A protein according to claim 64, wherein the cleavage site is E-F-S starting at approximately position 11 of native human pro-NGF.
66. A protein according to claim 64, wherein the cleavage site is E-L-S starting at approximately position 9 of native human pro-BDNF.
67. A protein according to claim 64, wherein the cleavage site is E-Y-S starting at approximately position 10 of native human pro-NT-3.
68. A protein according to claim 64, wherein the cleavage site is E-L-A starting at approximately position 13 of native human pro-NT-4/5.
69. A protein according to claim 46, wherein the LL cleavage site at approximately position 70 -71, approximately position 106-107 or approximately position 109-110 of pro-BDNF; or at approximately position 92-93 or approximately position 105-106 of pro-NT-3; or at approximately position 12-13, approximately position 13-14, approximately position 41-42, or approximately position 58-59 of pro-NT-4/5 is not present, and its replacement, if any, is protease cleavage resistant.
70. A protein according to claim 46, wherein at least one of the cleavage sites found approximately at positions 49-50 (R-R), 78-79 (K-K) 79-80 (K-R), 80-81(R-R), and 132-134 (E-F-S) of human pro-NGF is not present, and its replacement, if any, is protease cleavage resistant.
71. A protein according to claim 46, wherein at least one of the cleavage sites found approximately at positions 56-57 (L-T), 106-107 (L-L) 108-109 (F-L), 109-

110 (L-L), 111-112 (E-E), 134-135 (R-R), and 137-139 (E-L-S) of human pro-BDNF is not present, and its replacement, if any, is protease cleavage resistant.

72. A protein according to claim 46, wherein at least one of the cleavage sites found approximately at positions 92-93 (L-L), 97-98 (R-R), 105-106 (L-L), 148-150 (E-Y-S) of human pro-NT-3 is not present, and its replacement, if any, is protease cleavage resistant.

73. A protein according to claim 46, wherein at least one of the cleavage sites found approximately at positions 58-59 (L-L), 60-61 (F-L), 61-62 (L-L), 90-91 (R-R), and 93-95 (E-L-A) of human pro-NT-4/5 is not present, and its replacement, if any, is protease cleavage resistant.

74. A protein according to claim 46, wherein the protein is the pro form of nerve growth factor (pro-NGF), brain derived neurotrophic factor (pro-BDNF), neurotrophin 3 (pro-NT-3) or neurotrophin 4/5 (pro-NT4/5).

75. A protein according to claim 46, wherein the proneurotrophin is the pro form of brain derived neurotrophic factor.

76. A protein according to claim 46, wherein the protein is a monomer

77. A protein according to claim 46, wherein the protein is part of a multimer.

78. A protein according to claim 77, wherein the multimer is a dimer.

79. A protein according to claim 77, wherein the multimer is a trimer.

80. A protein according to claim 77, wherein the multimer is a heteromultimer.

81. A protein according to claim 77, wherein the multimer is a homomultimer.

82. A protein according to claim 46, wherein the protein is purified.
83. A protein according to claim 46 further comprising a pharmaceutically acceptable carrier.
84. A pharmaceutical composition that comprises a protein and a pharmaceutically acceptable additive, the protein comprising: (i) a pro-domain conserved region; (ii) a mature neurotrophin domain; and (iii) a connector that joins the pro-domain conserved region to the mature neurotrophin domain and that is resistant to protease cleavage.
85. A nucleic acid molecule that encodes a protein according to any of claim 1 to claim 20.
86. A nucleic acid molecule that encodes a modified proneurotrophin protein according to claim 46.
87. The nucleic acid molecule according to claim 86, wherein the nucleic acid is DNA or RNA.
88. A method for producing a protein according to claim 1, the method comprising expressing a nucleic acid molecule that encodes the protein in a host cell.
89. A method according to claim 88, wherein the host cell is prokaryotic.
90. A method according to claim 88, wherein the host cell is eukaryotic.
91. A method according to claim 90, wherein the host cell is a cell in a mammal.
92. A method according to claim 91, wherein the nucleic acid molecule has been injected into the cell.

93. A method according to claim 92, wherein the nucleic acid molecule is naked DNA.
94. A method according to claim 88 that is mediated by a viral vector.
95. A method according to claim 94, wherein the viral vector is an adenovirus.
96. A method according to claim 88 that is mediated by a liposome.
97. A method for producing a protein according to claim 46, the method comprising expressing a nucleic acid molecule that encodes the protein in a host cell.
98. A method according to claim 97, wherein the host cell is prokaryotic.
99. A method according to claim 97, wherein the host cell is eukaryotic.
100. A method according to claim 99, wherein the host cell is a cell in a mammal.
101. A method according to claim 100, wherein the nucleic acid molecule has been injected into the cell.
102. A method according to claim 101, wherein the nucleic acid molecule is naked DNA.
103. A method according to claim 97 that is mediated by a viral vector.
104. A method according to claim 103, wherein the viral vector is an adenovirus.
105. A method according to claim 97 that is mediated by a liposome.
106. A vector comprising a nucleic acid molecule that encodes a protein according to claim 1.

107. A vector comprising a nucleic acid molecule that encodes a modified proneurotrophin protein according to claim 46.
108. A host cell comprising a nucleic acid molecule according to claim 86.
109. A method for inducing apoptosis in a cell that comprises p75 receptors on its surface, the method comprising causing the p75 receptor to bind a modified proneurotrophin protein according to claim 46.
110. A method according to claim 109, wherein the cell is a malignant cell.
111. A method according to claim 110, wherein the malignant cell is a tumor cell.
112. A method according to claim 110, wherein the malignant cell is a melanoma cell.
113. A method according to claim 110, wherein the malignant cell is a prostate cell.
114. A method according to claim 110, wherein the malignant cell is a pancreatic cell.
115. A method according to claim 110, wherein the malignant cell is a nervous system cell.
116. A method according to claim 115, wherein the malignant nervous system cell is a medulloblastoma.
117. A method according to claim 115, wherein the malignant nervous system cell is an astrocytoma.

- 118. A method according to claim 110, wherein the malignant cell is a leukemic cell.
- 119. A method according to claim 110, wherein the malignant cell is a lymphoma.
- 120. A method according to claim 110, wherein the malignant cell is a testicular cell.
- 121. A method according to claim 110, wherein the malignant cell is a lung cell.
- 122. A method according to claim 110, wherein the malignant cell is a brain cell.
- 123. A method according to claim 111, wherein the tumor cell is a malignant oligodendrocyte.
- 124. A method according to claim 109, wherein the cell is a heart cell.
- 125. A method according to claim 109, wherein the cell is a vascular smooth muscle cell.
- 126. A method according to claim 109, wherein the vascular smooth muscle plaque is in an atherosclerotic plaque.
- 127. A method according to claim 109, wherein the cell is a neural cell.
- 128. A method according to claim 109 that occurs *in vitro*.
- 129. A method according to claim 109 that occurs in mammals in need thereof.
- 130. A method according to claim 129 that occurs in humans.

131. A method according to claim 130, wherein the proneurotrophin is administered to the human subcutaneously, intravenously, intramuscularly, intrathecally, or intraperitoneally.
132. A method according to claim 109, wherein the cell comprises a normal number of p75 receptors on its surface.
133. A method according to claim 109, wherein the cell comprises a higher than normal number of p75 receptors on its surface.
134. A method for cleaving a proneurotrophin protein to a mature neurotrophin, the method comprising contacting the proneurotrophin protein with MMP 3, MMP 7, or plasmin.
135. A method according to claim 134, wherein the proneurotrophin is pro-BDNF.
136. A method for inhibiting the cleavage of a proneurotrophin to a mature neurotrophin in a mammal in need thereof, the method comprising administering to the mammal an inhibitor of a protease that cleaves the major cleavage site found in native proneurotrophin proteins.
137. A method according to claim 136, wherein the protease is a serine protease.
138. A method according to claim 136, wherein the protease is a proprotein convertase.
139. A method according to claim 138, wherein the proprotein convertase is furin.
140. A method according to claim 136, wherein the inhibitor inhibits MMP-3, MM-7, a plasminogen activator, or plasmin.
141. A method according to claim 140, wherein the inhibitor is Ac-RCGVDP-NH₂.

142. A method for preventing or treating atherosclerosis in a mammal, the method comprising administering to the mammal an inhibitor of a protease that cleaves the major cleavage site found in native proneurotrophin proteins.
143. A method according to claim 142, wherein the protease is a serine protease.
144. A method according to claim 142, wherein the protease is a proprotein convertase.
145. A method according to claim 144, wherein the proprotein convertase is furin.
146. A method according to claim 142, wherein the inhibitor inhibits MMP-3, MM-7, a plasminogen activator, or plasmin.
147. A method according to claim 146, wherein the inhibitor is Ac-RCGVDP-NH₂.
148. A method for inducing cell apoptosis in a mammal in need thereof, wherein the cell is susceptible to apoptosis initiated by the binding of a proneurotrophin to a p75 receptor, the method comprising treating the mammal with an inhibitor of a protease that cleaves the major cleavage site found in native proneurotrophin proteins.
149. A method according to claim 148, wherein the protease is a serine protease.
150. A method according to claim 148, wherein the protease is a proprotein convertase.
151. A method according to claim 150, wherein the proprotein convertase is furin.
152. A method according to claim 148, wherein the inhibitor inhibits MMP-3, MM-7, a plasminogen activator, or plasmin.
153. A method according to claim 152, wherein the inhibitor is Ac-RCGVDP-NH₂.

154. A method for inducing apoptosis of cells expressing p75 receptors and trk receptors in a mammal in need thereof, the method comprising administering to the mammal an effective amount of a cleavage-resistant proneurotrophin and an inhibitor of trk activation.
155. A method according to claim 154, wherein the inhibitor of trk activation is an indolecarbazole derivative.
156. A method according to claim 154, wherein the indolecarbazole derivative is K252a.
157. A method for inhibiting apoptosis of a cell in a mammal in need thereof, the method comprising administering to the mammal an effective amount of a molecule that inhibits the binding of a proneurotrophin to a p75 receptor.
158. A method according to claim 157, wherein the proneurotrophin is NGF.
159. A method according to claim 157, wherein the proneurotrophin is BDNF.
160. A method according to claim 157, wherein the proneurotrophin is NT-3.
161. A method according to claim 157, wherein the proneurotrophin is NT-4/5.
162. A method according to claim 157, wherein the cell is a cell of the nervous system.
163. A method according to claim 162, wherein the cell is a cell of the central nervous system.
164. A method according to claim 162, wherein the cell is a cell of the peripheral nervous system.

- 165. A method according to claim 162, wherein the cell is a neuron.
- 166. A method according to claim 162, wherein the cell is a glia cell.
- 167. A method according to claim 166, wherein the cell is an oligodendrocyte.
- 168. A method according to claim 166, wherein the cell is a Schwann cell.
- 169. A method according to claim 166, wherein the cell is an astrocyte.
- 170. A method according to claim 157, wherein the cell is a component of a hair follicle.
- 171. A method according to claim 170, wherein the cell is a keratinocyte.
- 172. A method according to claim 170, wherein the cell is an epithelial cell.
- 173. A method according to claim 170, wherein the cell is a testicular cell.
- 174. A method according to claim 170, wherein the cell is a lung cell.
- 175. A method according to claim 170, wherein the cell is a brain cell.
- 176. A method according to claim 170, wherein the cell is a heart cell.
- 177. A method according to claim 157, wherein the molecule binds specifically to the p75 receptor.
- 178. A method according to claim 177, wherein the molecule comprises the hypervariable region of an antibody.

179. A method according to claim 178, wherein the molecule comprises the variable region of an antibody.
180. A method according to claim 178, wherein the molecule is an antibody.
181. A method according to claim 180, wherein the antibody is a chimeric antibody.
182. A method according to claim 180, wherein the antibody is a humanized antibody.
183. A method according to claim 178, wherein the molecule is a single chain antibody.
184. A method according to claim 177, wherein the molecule comprises an oligopeptide having the formula:



wherein Z represents any alpha amino acid and.

185. A method according to claim 184, wherein z represents any number from 0 to approximately 10.
186. A method according to claim 184, wherein z represents any number from 0 to approximately 5.
187. A method according to claim 184, wherein the oligopeptide is cyclic.
188. A method according to claim 157, wherein the molecule binds specifically to the proneurotrophin.

189. A method according to claim 188, wherein the molecule comprises an extracellular domain of a p75 receptor, and lacks an intracellular domain and a trans-membrane domain.
190. A method according to claim 189, wherein the molecule comprises a receptor body.
191. A method according to claim 189, wherein the molecule comprises the extracellular domain in a soluble form.
192. A method according to claim 188, wherein the molecule comprises the hypervariable region of an antibody.
193. A method according to claim 192, wherein the molecule comprises the variable region of an antibody .
194. A method according to claim 192, wherein the molecule is an antibody.
195. A method according to claim 194, wherein the antibody is a chimeric antibody.
196. A method according to claim 194, wherein the antibody is a humanized antibody.
197. A method according to claim 192, wherein the molecule is a single chain antibody.
198. A method according to claim 192, wherein the proneurotrophin is part of a multimer of proneurotrophins.
199. A method according to claim 198, wherein the multimer is a dimer.

- 200. A protein according to claim 198, wherein the multimer is a trimer.
- 201. A protein according to claim 198, wherein the multimer is a heteromultimer.
- 202. A protein according to claim 198, wherein the multimer is a homomultimer.
- 203. A method according to claim 192, wherein the proneurotrophin is NGF.
- 204. A method according to claim 192, wherein the proneurotrophin is BDNF.
- 205. A method according to claim 192, wherein the proneurotrophin is NT-3.
- 206. A method according to claim 192, wherein the proneurotrophin is NT-4/5.
- 207. A method according to claim 157, wherein the molecule is a protease that cleaves the proneurotrophin to form a mature neurotrophin.
- 208. A method according to claim 207, wherein the protease is a serine protease.
- 209. A method according to claim 207, wherein the protease is a pro-protein convertase.
- 210. A method according to claim 207, wherein the protease is a furin.
- 211. A method according to claim 207, wherein the protease is plasmin.
- 212. A method according to claim 207, wherein the protease is a matrix metalloproteinase.

213. A method according to claim 212, wherein the matrix metalloproteinase is MMP-3 or MMP-7.
214. A method according to claim 157, wherein the mammal is a human.
215. A method according to claim 214, wherein the human suffers from a condition associated with undesired apoptosis due to binding of a proneurotrophin to a p75 receptor.
216. A method according to claim 215, wherein the p75 receptor, the proneurotrophin, or both are overexpressed in the human.
217. A method according to claim 215, wherein the condition is the result of an injury or an environmental insult.
218. A method according to claim 217, wherein the injury or environmental insult is a nervous system injury.
219. A method according to claim 217, wherein the injury or environmental insult is caused by a chemical or radiation.
220. A method according to claim 217, wherein the injury or environmental insult occurs during treatment for cancer.
221. A method according to claim 215, wherein the condition is hypoxic ischemia.
222. A method according to claim 221, wherein the hypoxic ischemia is caused by a stroke.
223. A method according to claim 221, wherein the hypoxic ischemia is caused by a heart attack.

224. A method according to claim 215, wherein the condition is caused by a viral or microbial infection.
225. A method according to claim 224, wherein the condition is meningitis, encephalitis, or abscesses.
226. A method according to claim 224, wherein the microbial infection is a viral infection.
227. A method according to claim 224, wherein the microbial infection is a bacterial infection.
228. A method according to claim 215, wherein the condition is a neurodegenerative disorder.
229. A method according to claim 215, wherein the condition is Alzheimer's disease, familial dysautonomia, ataxia telangiectasia, Charcot-Marie-Tooth disease, Adreno leuko dystrophy, spinal muscular atrophy, Friedreich's ataxia.
230. A method according to claim 215, wherein the condition is multiple sclerosis.
231. A method according to claim 215, wherein the condition causes convulsions.
232. A method according to claim 231, wherein the condition is epilepsy.
233. A method according to claim 218, wherein the condition is spinal cord injury.
234. A method to screen a human patient for a condition associated with undesired apoptosis, the method comprising determining whether the level of at least one proneurotrophin, or of a conjugate between a p75 receptor and at least one proneurotrophin, in a biological sample of the patient is elevated, wherein elevated

levels of proneurotrophins or p75/proneurotrophin conjugates indicate the existence of the condition.

235. A method according to claim 234, wherein the condition is hypoxic ischemia.

236. A method according to claim 234, wherein the condition is caused by a viral or microbial infection.

237. A method according to claim 236, wherein the condition is meningitis, encephalitis, or abscesses.

238. A method according to claim 234, wherein the condition is a neurodegenerative disorder.

239. A method according to claim 234, wherein the condition is Alzheimer's disease, familial dysautonomia, ataxia telangiectasia, Charcot-Marie-Tooth disease, Adreno leuko dystrophy, spinal muscular atrophy, Friedreich's ataxia.

240. A method according to claim 234, wherein the condition is multiple sclerosis.

241. A method according to claim 234, wherein the condition causes convulsions.

242. A method according to claim 241, wherein the condition is epilepsy.

243. A method according to claim 234, wherein the biological sample is blood, urine, hair, cheek scrapings, semen, tissue biopsy, and saliva.

244. A method according to claim 234, wherein the level is determined by contacting the biological sample with a probe, detecting the probe, and ascertaining whether the level of the probe is elevated relative to a human who does not have the condition.

245. A method according to claim 244, wherein the probe is labeled.
246. A method according to claim 244, wherein the probe comprises an antibody.
247. A method according to claim 244, wherein the probe comprises the extracellular region of a p75 receptor.
248. A method according to claim 247, wherein the probe comprises a receptor body.
249. A method for inhibiting apoptosis-mediated hair follicle regression in a mammal in need thereof, the method comprising administering to the mammal an effective amount of a molecule that inhibits the binding of a proneurotrophin to a p75 receptor.

**Figure 1A: Primary Protein Sequence from Human NGF
(Gen Bank Accession Number: AAA59931)**

1 msnlfytlit afligiqae hseenvpagh tipqvhwtkl qhsldtalrr arsapaaaia
61 arvaggqtrni tvdprlflkr rlrspvrlfs tqppreaadt qdlldfevgga apfnrthrsk
121 rsshpihfr gefsvcdsvs vwgdkttat dikgkevmvl gevninnsvf kqyffetkcr
181 dpnpvdgcr gidskhwnsy ctthtftvka ltmdgkqaaw rffridtacv cvlsrkavrr
241 a

Figure 1B: Schematic Representation of Monomeric, Un-glycosylated NGF Isoforms According to Prior Art

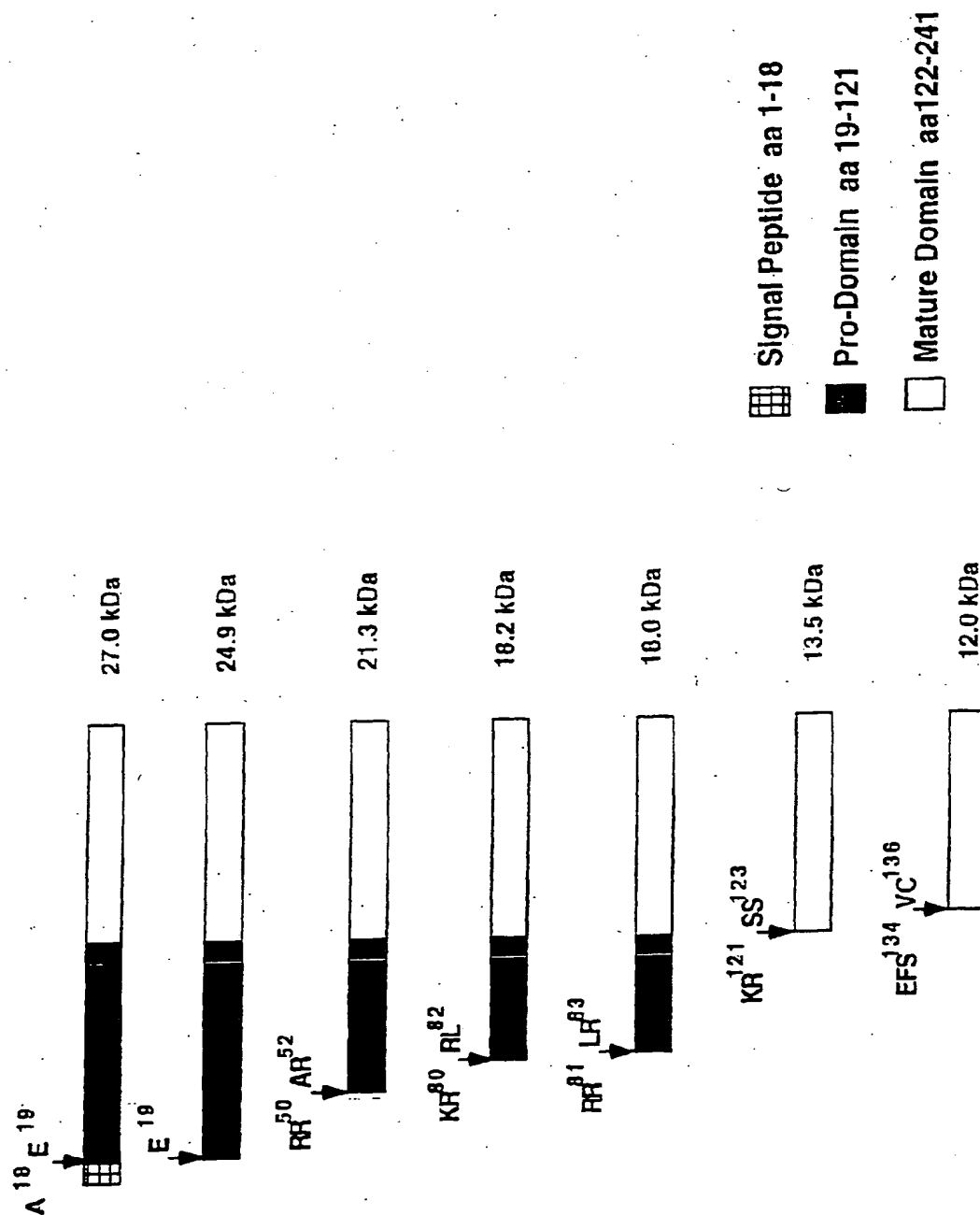
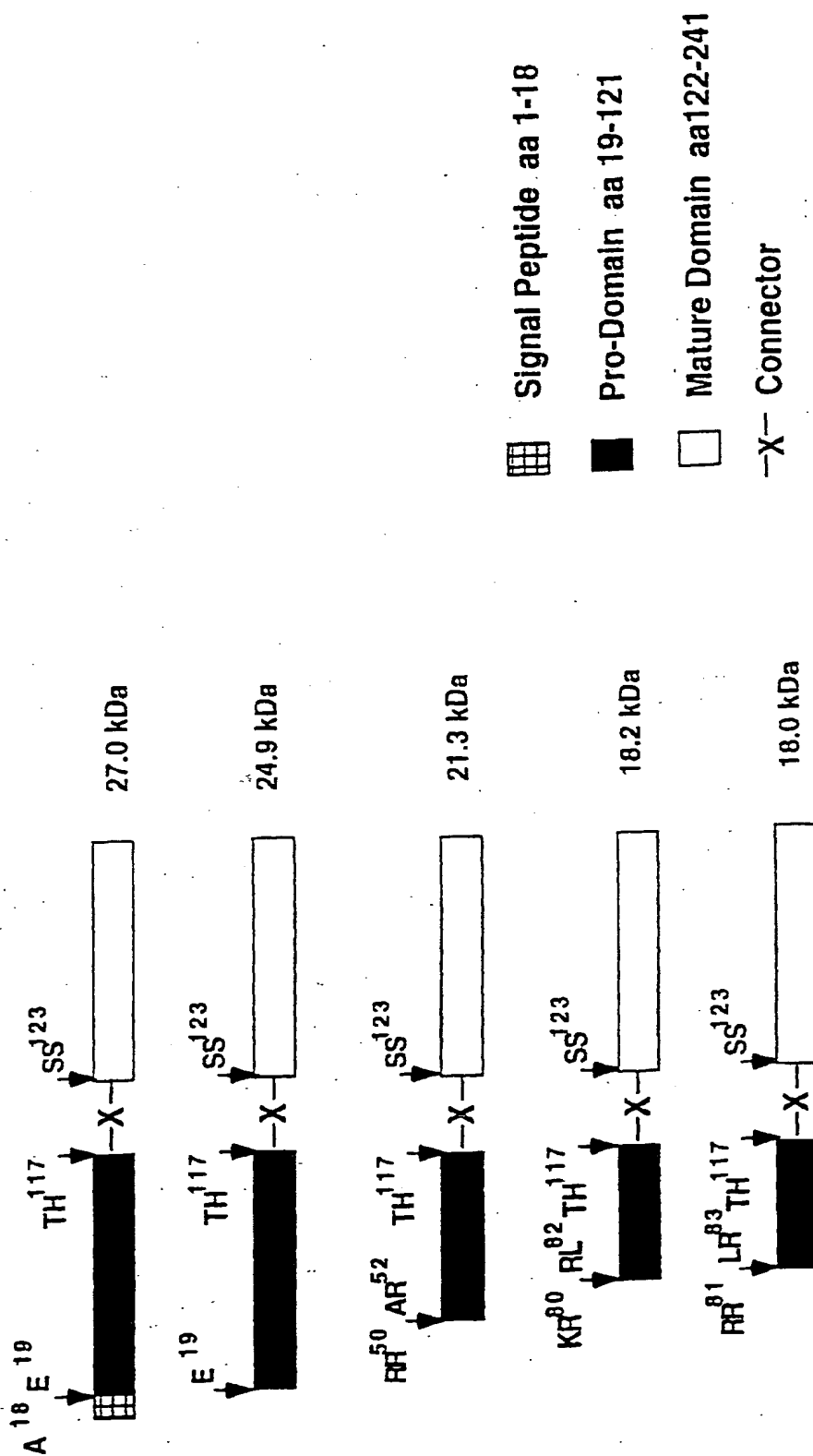


Figure 1C: Schematic Representation of Modified Pro-NGF According to Invention



**Figure 2A: Primary Protein Sequence from Human BDNF
(Gen Bank Accession Number: AAA69805)**

```
1  mtilfltmvi syfgcmkaap mkeanirgqg glaypgvrth gtlesvngpk agargltsla
61  dtfehvieel ldedqkvrpn eenkdadly tsrvmlssqv plepplflf1 eeyknyldaa
121 nmsmrvrhrs dparrgelav cdsisewrta adkktavdms ggtvtvlekv pvskgqlkqy
181 fyetkcnpmg ytkegcrgid krhwnsqcrt tqsyvraltm dskkrigwrf iridtsacvct
241 ltikrgr
```

Figure 2B: Schematic Representation of Monomeric, Un-glycosylated BDNF Isoforms According to Prior Art

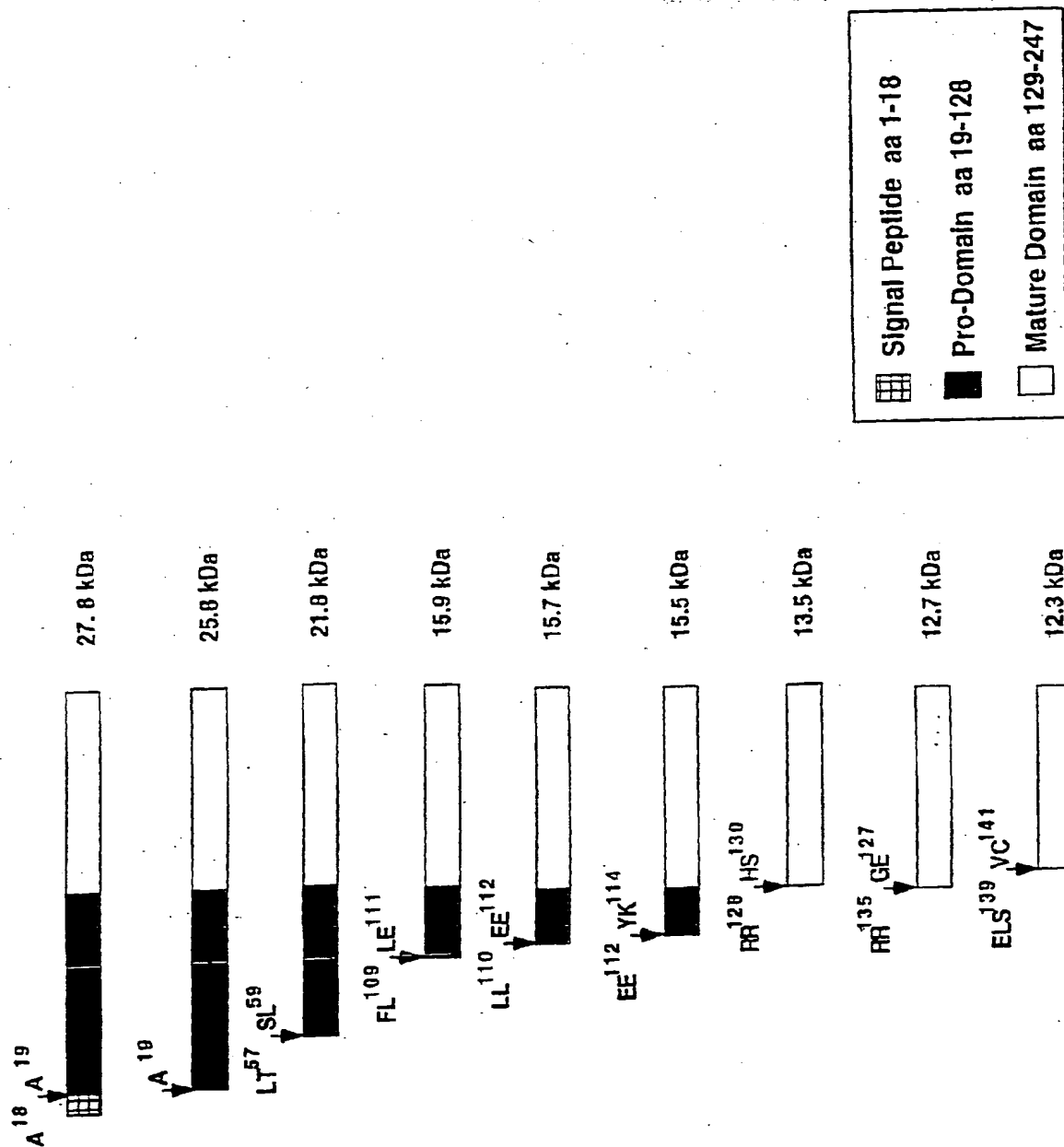
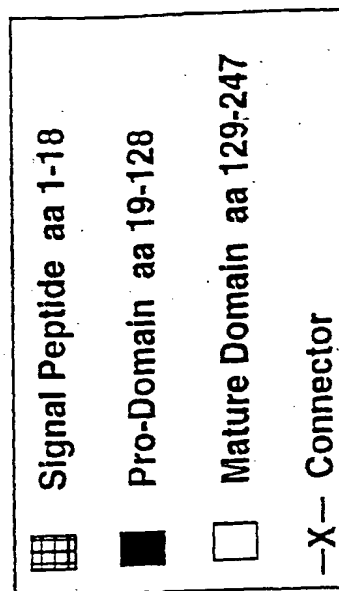
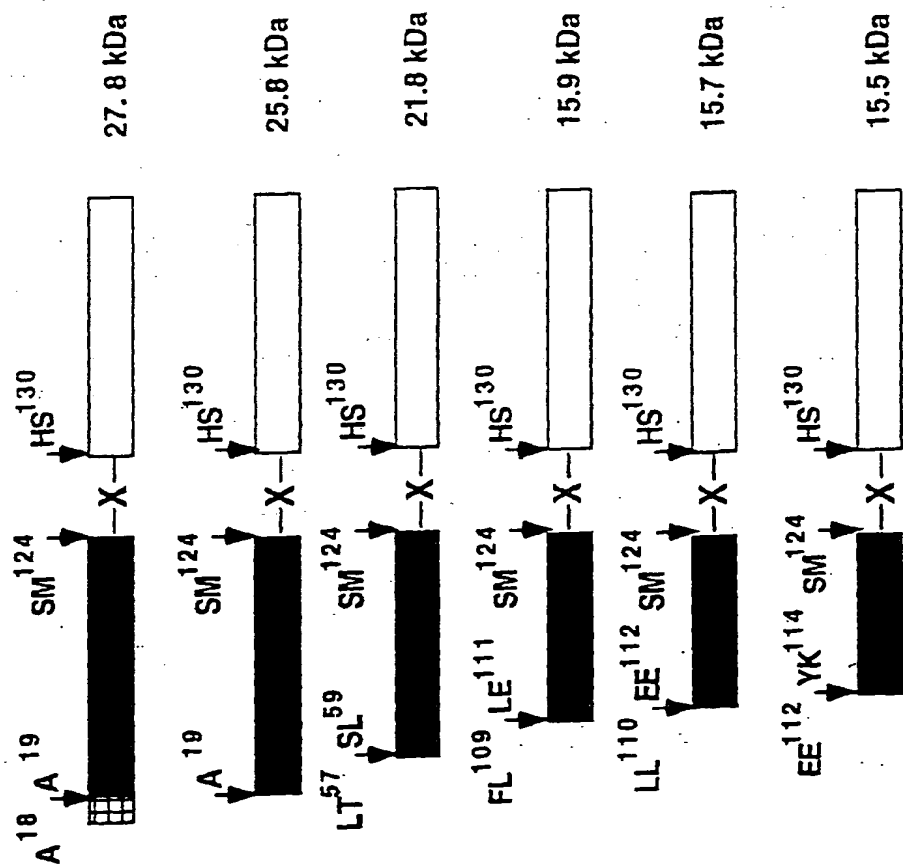


Figure 2C: Schematic Representation of Modified Pro-BDNF According to Invention



**Figure 3A: Primary Protein Sequence from Human NT-3
(Gen Bank Accession Number: AAA59953)**

1 msilfyvifl aylrgiqgnn mdqrslpeds lnsliikliq adilknlak qmvdvkenyq
61 stlpkaeapr eperggpaks afqpviandt ellrqrrryn sprvllsdt pleppplylm
121 edyvgspvva nrtsrkrkrya ehkshrgays vcdseslwvt dkssaidirg hqvtvlgeik
181 tgnspvkqyf yetrckearp vkngcrgidd khwnsqckts qtyvraltse nnklvgwrwi
241 ridtscvcal srkigrt

Figure 3B: Schematic Representation of Monomeric, Un-glycosylated NT-3 Isoforms According to Prior Art

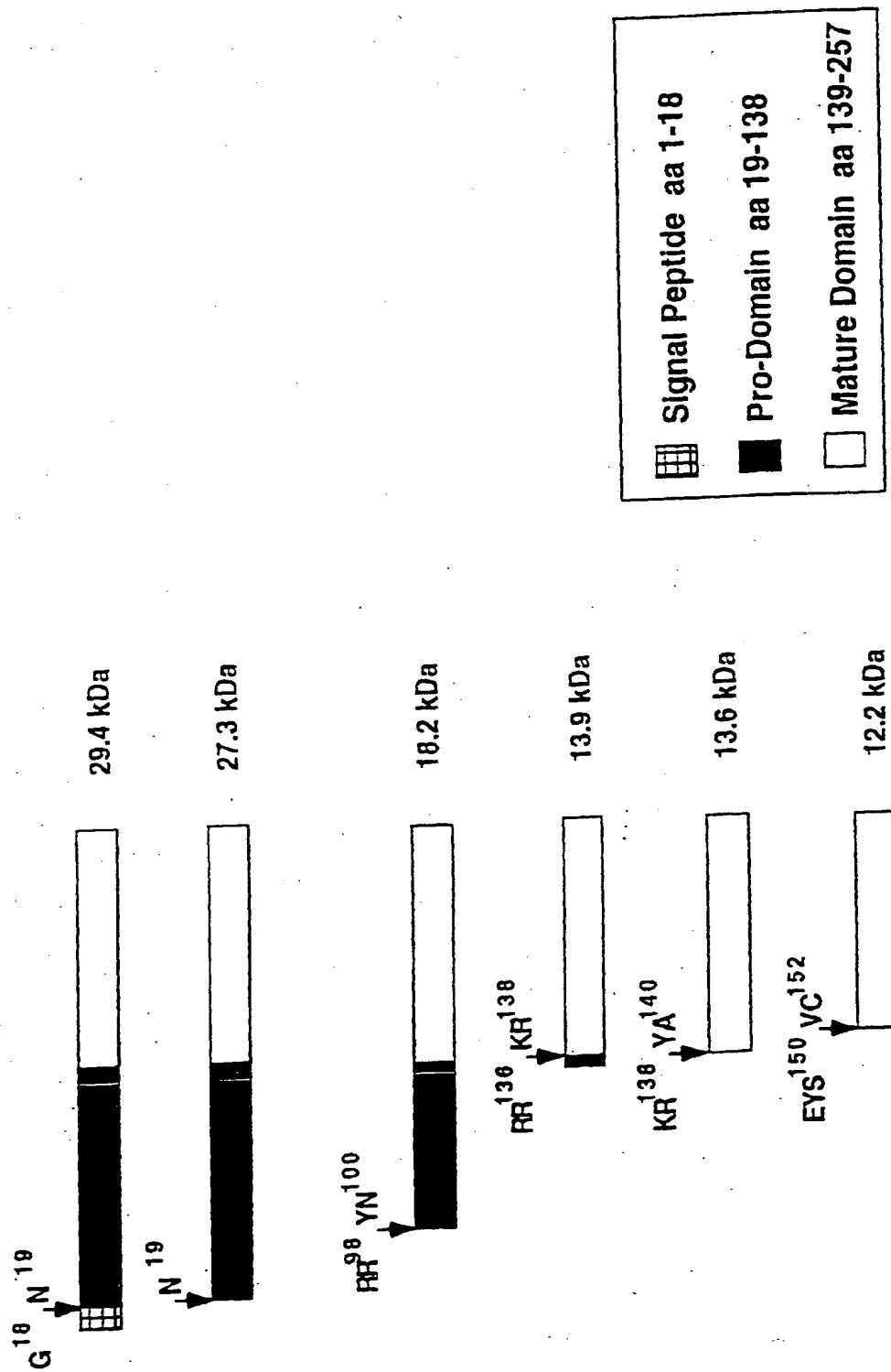
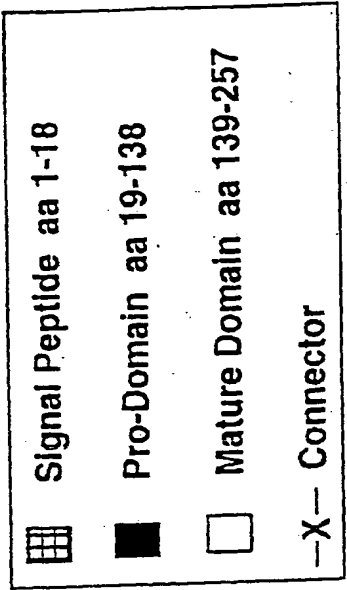
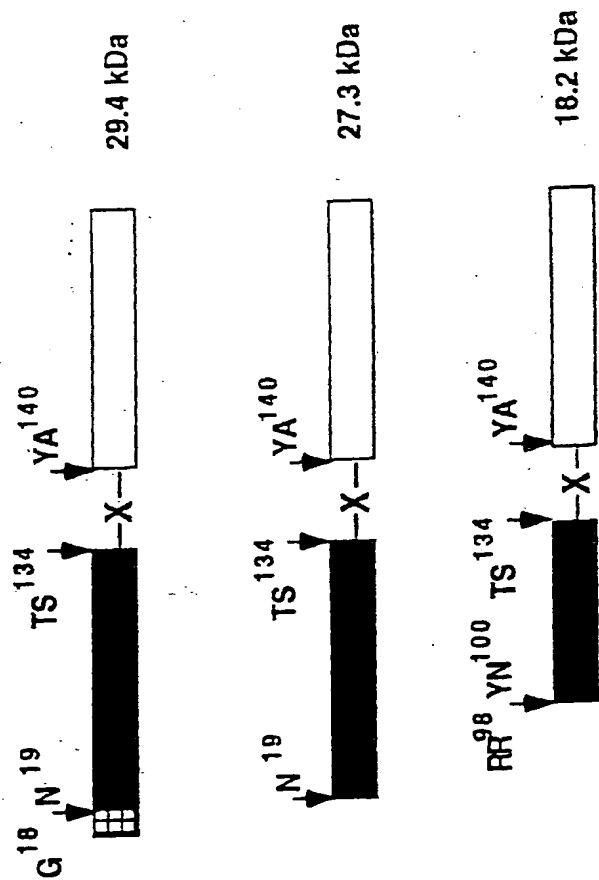


Figure 3C: Schematic Representation of Modified Pro-NT-3 According to Invention



**Figure 4A: Primary Protein Sequence from Human NT-4/5
(Gen Bank Accession Number: AAA60154 & AAA20549)**

```
1 mlplpscslp illflflpsv piesqpppst lppflapewd llsprvvlr gapagppllf
61 lleagafres agapanrsrr gvsetapasr rgelavcdav sgwtdnrta vdlrgrevev
121 lgevpaaggs plrqyffetr ckadnaeegg pgaggggcrig vdirhwvsec kakqsyvral
181 tadaqgrvgw rwiridtacv ctllsrtgra
```

Figure 4B: Schematic Representation of Monomeric, Un-glycosylated NT-4/5 Isoforms According to Prior Art

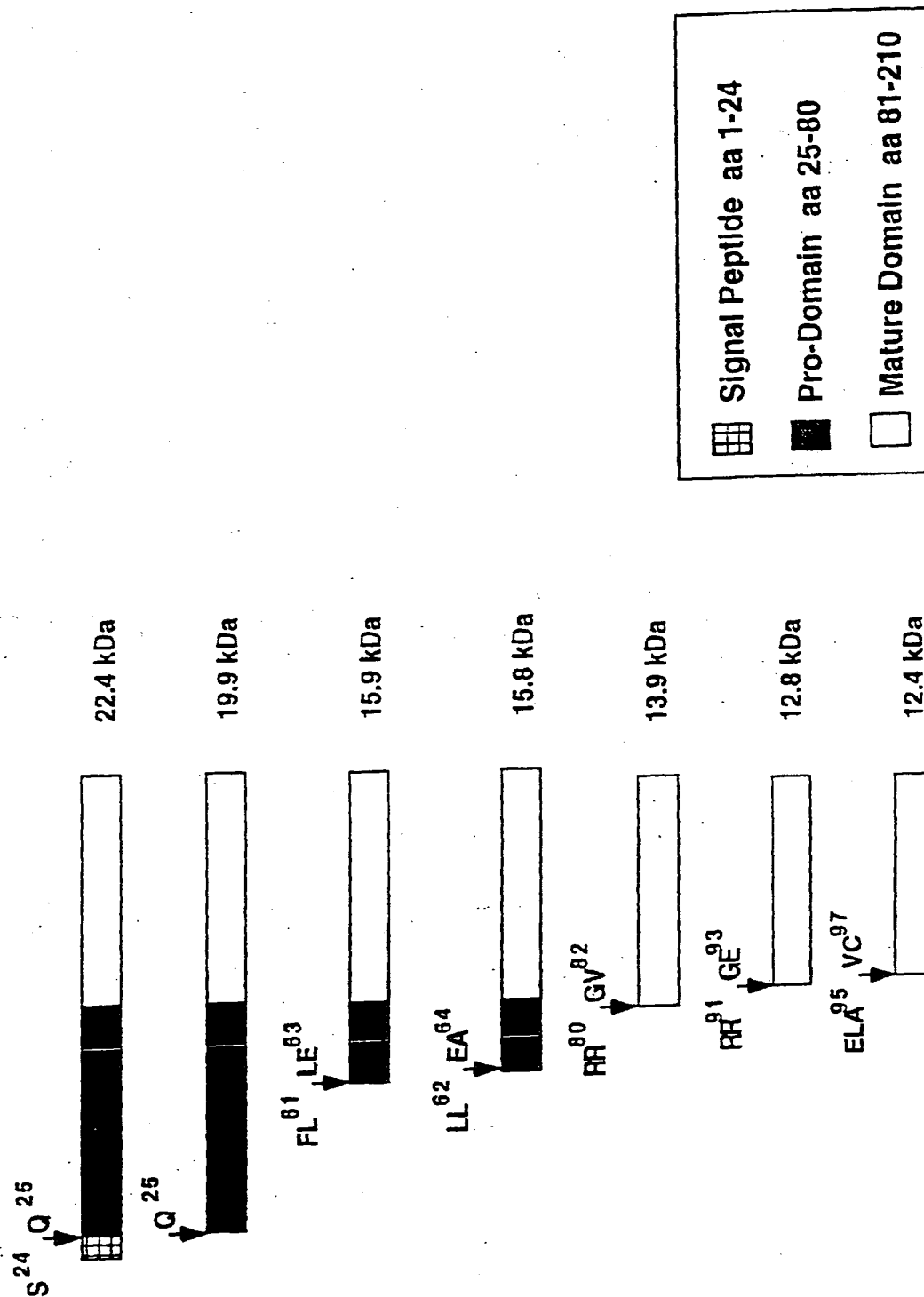
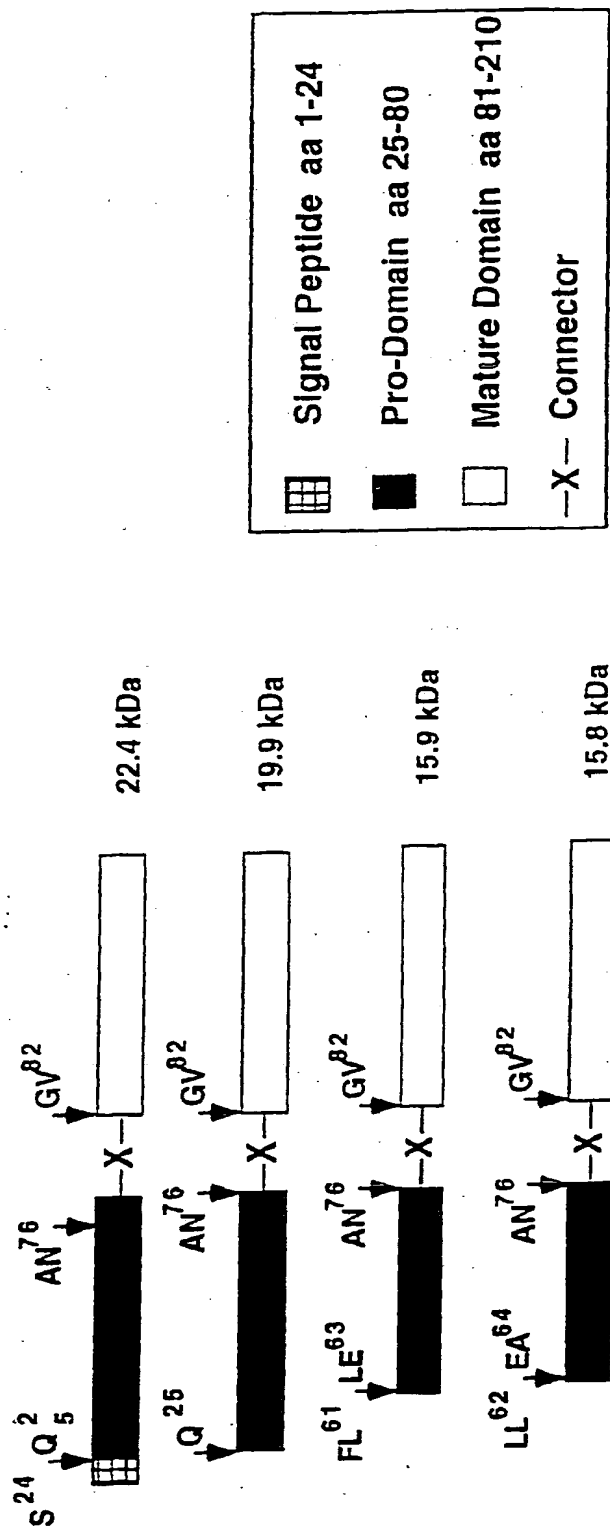



Figure 4C: Schematic Representation of Modified Pro-NT-4/5 According to Invention



Human p75 Receptor Sequence (Accession Number: g69056)

```

1  mqaatqram dqprllllll lqvelqqake apuqllytha qeckaenlg egvaqpcgan
61  qirvcepolas vbedvrsat eockpctecv glqamsapkv eadeavercd ygyvqdetug
121  cceagayveea gggvfaqqd kntvssesp qglvysdeanh ydpclpetve edterqlreQ
181  kwadaecee ypqzllrsb ppgssstap algebeappe qdlrast ag wltvngabq
241  ewtgrguah llpvycaila avvqlvayi afkrwnackg nkqganrpy nqtpppegek
301  lhdsqisvd sqslhdqqph tqtasgqalk gdgglysslp pakreevekl lngsagdtwr
361  hlqgelgyqp ehidsfthea cpvrallaw atqdsatlida llaalrrigr adveslcbe
421  statgpy
    
```

 Signal Sequence

 Extracellular Domain


 Transmembrane and Intracellular Domain

Figure 4D

Sequence Comparison for Human Neurotrophin Family Members

[illegible]

Signal Sequence

Pro-Neurotrophin Domain

Mature Neurotrophin Domain

Identical Amino Acid Sequence

Conservative Amino Acid Substitution

Significant Homology Across Members

Figure 5A

Sequence Comparison for NGF across Species

Human (P01118)	MSMLPTTLTATLTHGCHLPHGESHNP-----AGHTIPQVINTKLOH
Gorilla (BA090439)	MSMLPTTLTATLTHGCHLPHGESHNP-----AGHTIPQVINTKLOH
Rat (P25427)	MSMLPTTLTATLTHGCHLPHGESHNP-----AGHTIPQVINTKLOH
Mouse (P01139)	MSMLPTTLTATLTHGCHLPHGESHNP-----AGHTIPQVINTKLOH
Bovine (CA070759)	MSMLPTTLTATLTHGCHLPHGESHNP-----AGHTIPQVINTKLOH
Chicken (I052509)	MSMLPTTLTATLTHGCHLPHGESHNP-----AGHTIPQVINTKLOH
Xenopus (CAA39249)	MSMLPTTLTATLTHGCHLPHGESHNP-----AGHTIPQVINTKLOH
Human (P01138)	SLQTLARARARAPAAIAAARVAGTTHITVDPLPKRRLRSPRVLFSTQ
Gorilla (BA090439)	SLQTLARARARAPAAIAAARVAGTTHITVDPLPKRRLRSPRVLFSTQ
Rat (P25427)	SLQTLARARARAPAAIAAARVAGTTHITVDPLPKRRLRSPRVLFSTQ
Mouse (P01139)	SLQTLARARARAPAAIAAARVAGTTHITVDPLPKRRLRSPRVLFSTQ
Bovine (CA070759)	SLQTLARARARAPAAIAAARVAGTTHITVDPLPKRRLRSPRVLFSTQ
Chicken (I052509)	SLQTLARARARAPAAIAAARVAGTTHITVDPLPKRRLRSPRVLFSTQ
Xenopus (CAA39249)	SLQTLARARARAPAAIAAARVAGTTHITVDPLPKRRLRSPRVLFSTQ
Human (P01138)	PPPEAADTDLDPFVSGVAAFNHTRHRSKSSHPHIFRGFSVCDVSVM
Gorilla (BA090439)	PPPEAADTDLDPFVSGVAAFNHTRHRSKSSHPHIFRGFSVCDVSVM
Rat (P25427)	PPPEAADTDLDPFVSGVAAFNHTRHRSKSSHPHIFRGFSVCDVSVM
Mouse (P01139)	PPPEAADTDLDPFVSGVAAFNHTRHRSKSSHPHIFRGFSVCDVSVM
Bovine (CA070759)	PPPEAADTDLDPFVSGVAAFNHTRHRSKSSHPHIFRGFSVCDVSVM
Chicken (I052509)	PPPEAADTDLDPFVSGVAAFNHTRHRSKSSHPHIFRGFSVCDVSVM
Xenopus (CAA39249)	PPPEAADTDLDPFVSGVAAFNHTRHRSKSSHPHIFRGFSVCDVSVM
Human (P01138)	WGDKTTATDGGKGVNVIJZVNNINNSVFKQYFEETKCRDHPVDSCGRI
Gorilla (BA090439)	WGDKTTATDGGKGVNVIJZVNNINNSVFKQYFEETKCRDHPVDSCGRI
Rat (P25427)	WGDKTTATDGGKGVNVIJZVNNINNSVFKQYFEETKCRDHPVDSCGRI
Mouse (P01139)	WGDKTTATDGGKGVNVIJZVNNINNSVFKQYFEETKCRDHPVDSCGRI
Bovine (CA070759)	WGDKTTATDGGKGVNVIJZVNNINNSVFKQYFEETKCRDHPVDSCGRI
Chicken (I052509)	WGDKTTATDGGKGVNVIJZVNNINNSVFKQYFEETKCRDHPVDSCGRI
Xenopus (CAA39249)	WGDKTTATDGGKGVNVIJZVNNINNSVFKQYFEETKCRDHPVDSCGRI
Human (P01138)	DSKHNISYCTTTHFVKALTMGKQAAMRFIRIDTACVCVLSKRAVRA
Gorilla (BA090439)	DSKHNISYCTTTHFVKALTMGKQAAMRFIRIDTACVCVLSKRAVRA
Rat (P25427)	DSKHNISYCTTTHFVKALTMGKQAAMRFIRIDTACVCVLSKRAVRA
Mouse (P01139)	DSKHNISYCTTTHFVKALTMGKQAAMRFIRIDTACVCVLSKRAVRA
Bovine (CA070759)	DSKHNISYCTTTHFVKALTMGKQAAMRFIRIDTACVCVLSKRAVRA
Chicken (I052509)	DSKHNISYCTTTHFVKALTMGKQAAMRFIRIDTACVCVLSKRAVRA
Xenopus (CAA39249)	DSKHNISYCTTTHFVKALTMGKQAAMRFIRIDTACVCVLSKRAVRA

Signal Sequence

Mature NGF Domain

Identical Amino Acid Sequence

Conservative Amino Acid Substitution

Significant Homology Across Species

Figure 5B.

Sequence Comparison for BDNF across Species

[illegible]

Signal Sequence

 Pro-BDNF Domain

Mature BDNF Domain

Identical Amino Acid Sequence

Conservative Amino Acid Substitution

Significant Homology Across Species

Figure 5C

Sequence Comparison for NT-3 across Species

Human (AAA59953)	MSLFLVYFIPLAVLPGLGICNNMDQSRSLPBDLSNLIIKLQADILKNKLSK
Rat (AAB11721)	MSLFLVYFIPLAVLPGLGICNNMDQSRSLPBDLSNLIIKLQADILKNKLSK
Mouse (CAA37348)	MSLFLVYFIPLAVLPGLGICNNMDQSRSLPBDLSNLIIKLQADILKNKLSK
Chick (AAAG8880)	MSLFLVYFIPLAVLPGLGICNNMDQSRSLPBDLSNLIIKLQADILKNKLSK
Xenopus (AAB17723)	MSLFLVYFIPLAVLPGLGICNNMDQSRSLPBDLSNLIIKLQADILKNKLSK
Human (AAA59953)	QWVDKENVQSTLPKAEAPREPRGQPAKSAFQPVAMDTELLROO--RR
Rat (AAB11721)	QWVDKENVQSTLPKAEAPREPRGQPAKSAFQPVAMDTELLROO--RR
Mouse (CAA37348)	QWVDKENVQSTLPKAEAPREPRGQPAKSAFQPVAMDTELLROO--RR
Chick (AAAG8880)	QWVDKENVQSTLPKAEAPREPRGQPAKSAFQPVAMDTELLROO--RR
Xenopus (AAB17723)	QWVDKENVQSTLPKAEAPREPRGQPAKSAFQPVAMDTELLROO--RR
Human (AAA59953)	YNSPRVLLSDSTPLEPPPLVLMEDYVGNPVVNRTS-RRKRYAEHKSHRG
Rat (AAB11721)	YNSPRVLLSDSTPLEPPPLVLMEDYVGNPVVNRTS-RRKRYAEHKSHRG
Mouse (CAA37348)	YNSPRVLLSDSTPLEPPPLVLMEDYVGNPVVNRTS-RRKRYAEHKSHRG
Chick (AAAG8880)	YNSPRVLLSDSTPLEPPPLVLMEDYVGNPVVNRTS-RRKRYAEHKSHRG
Xenopus (AAB17723)	YNSPRVLLSDSTPLEPPPLVLMEDYVGNPVVNRTS-RRKRYAEHKSHRG
Human (AAA59953)	EYSVCDSBSLWVTUKSSAIDIRGHQVTVLGEIKTGNSPVKQFYETRCKE
Rat (AAB11721)	EYSVCDSBSLWVTUKSSAIDIRGHQVTVLGEIKTGNSPVKQFYETRCKE
Mouse (CAA37348)	EYSVCDSBSLWVTUKSSAIDIRGHQVTVLGEIKTGNSPVKQFYETRCKE
Chick (AAAG8880)	EYSVCDSBSLWVTUKSSAIDIRGHQVTVLGEIKTGNSPVKQFYETRCKE
Xenopus (AAB17723)	EYSVCDSBSLWVTUKSSAIDIRGHQVTVLGEIKTGNSPVKQFYETRCKE
Human (AAA59953)	ARPVKNGCRGIDDKIHNSOCKTSQTVVRALTSENNKLVGWRWIRIDTSCV
Rat (AAB11721)	ARPVKNGCRGIDDKIHNSOCKTSQTVVRALTSENNKLVGWRWIRIDTSCV
Mouse (CAA37348)	ARPVKNGCRGIDDKIHNSOCKTSQTVVRALTSENNKLVGWRWIRIDTSCV
Chick (AAAG8880)	ARPVKNGCRGIDDKIHNSOCKTSQTVVRALTSENNKLVGWRWIRIDTSCV
Xenopus (AAB17723)	ARPVKNGCRGIDDKIHNSOCKTSQTVVRALTSENNKLVGWRWIRIDTSCV
Human (AAA59953)	CALSRKIGRT
Rat (AAB11721)	CALSRKIGRT
Mouse (CAA37348)	CALSRKIGRT
Chick (AAAG8880)	CALSRKIGRT
Xenopus (AAB17723)	CALSRKIGRT

Signal Sequence

Pro-NT-3 Domain

Mature NT-3 Domain

Identical Amino Acid Sequence

Conservative Amino Acid Substitution

Significant Homology Across Species

Figure 5D

Sequence Comparison for NT-4/5 across Species


Human (AAA60154)
Rat (AAA41728)
Xenopus (CAA82306)

Human (AAA60154)
Rat (AAA41728)
Xenopus (CAA82306)

Human (AAA60154)
Rat (AAA41728)
Xenopus (CAA82306)

Human (AAA60154)
Rat (AAA41728)
Xenopus (CAA82306)

Signal Sequence

 Pro-NT-4/5 Domain

Malure NT-4/5 Domain

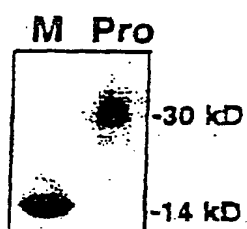
* **Identical Amino Acid Sequence**

Conservative Amino Acid Substitution

Significant Homology Across Species

Figure 5E

FIGURE 6



M= mature

Pro = cleavage resistant pro-NGF

Figure 7

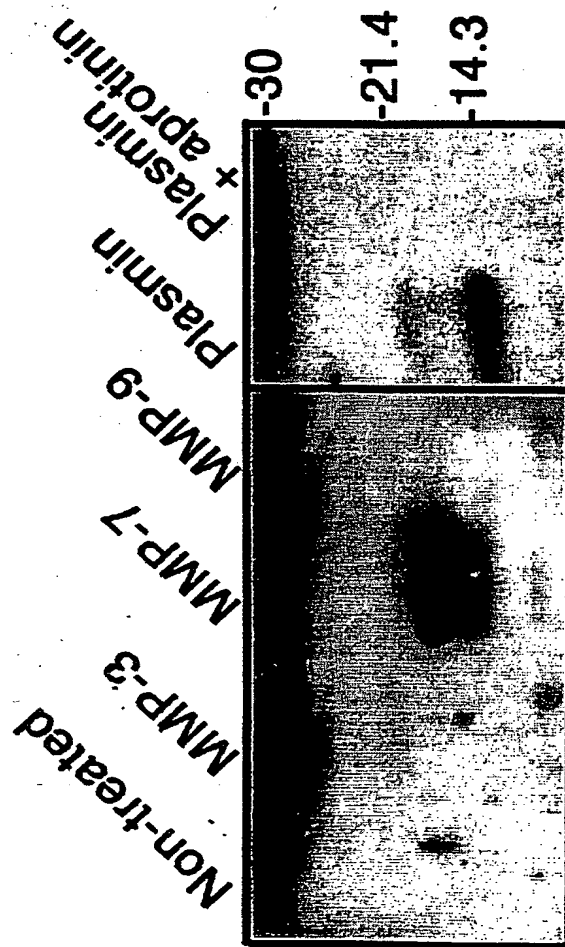


Figure 8

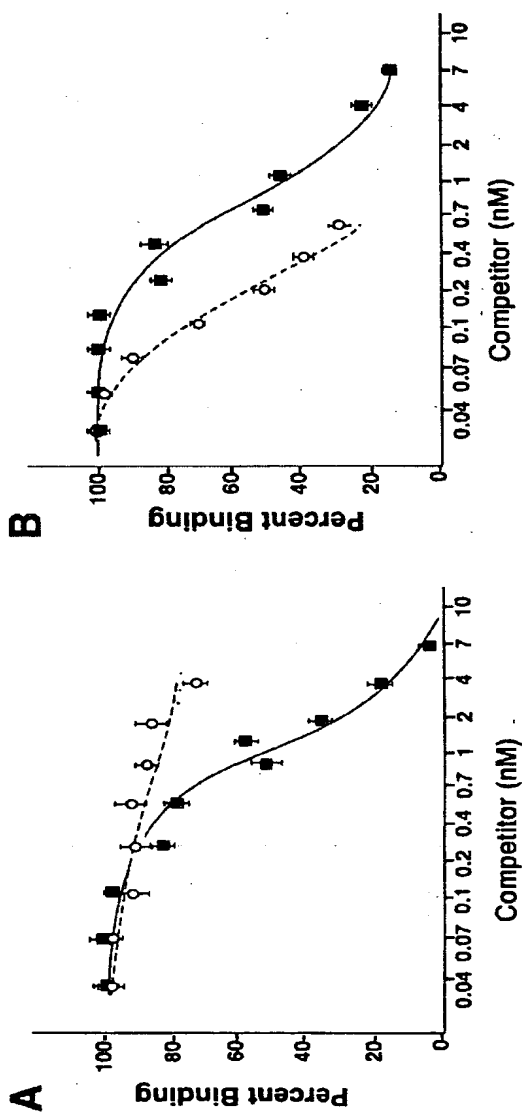


Figure 9

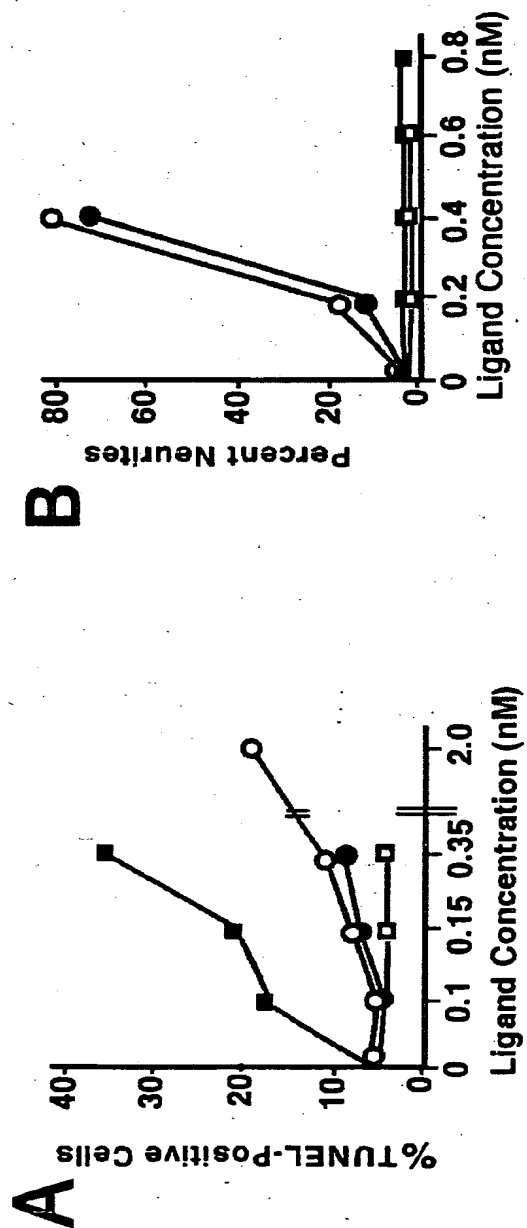


Figure 9

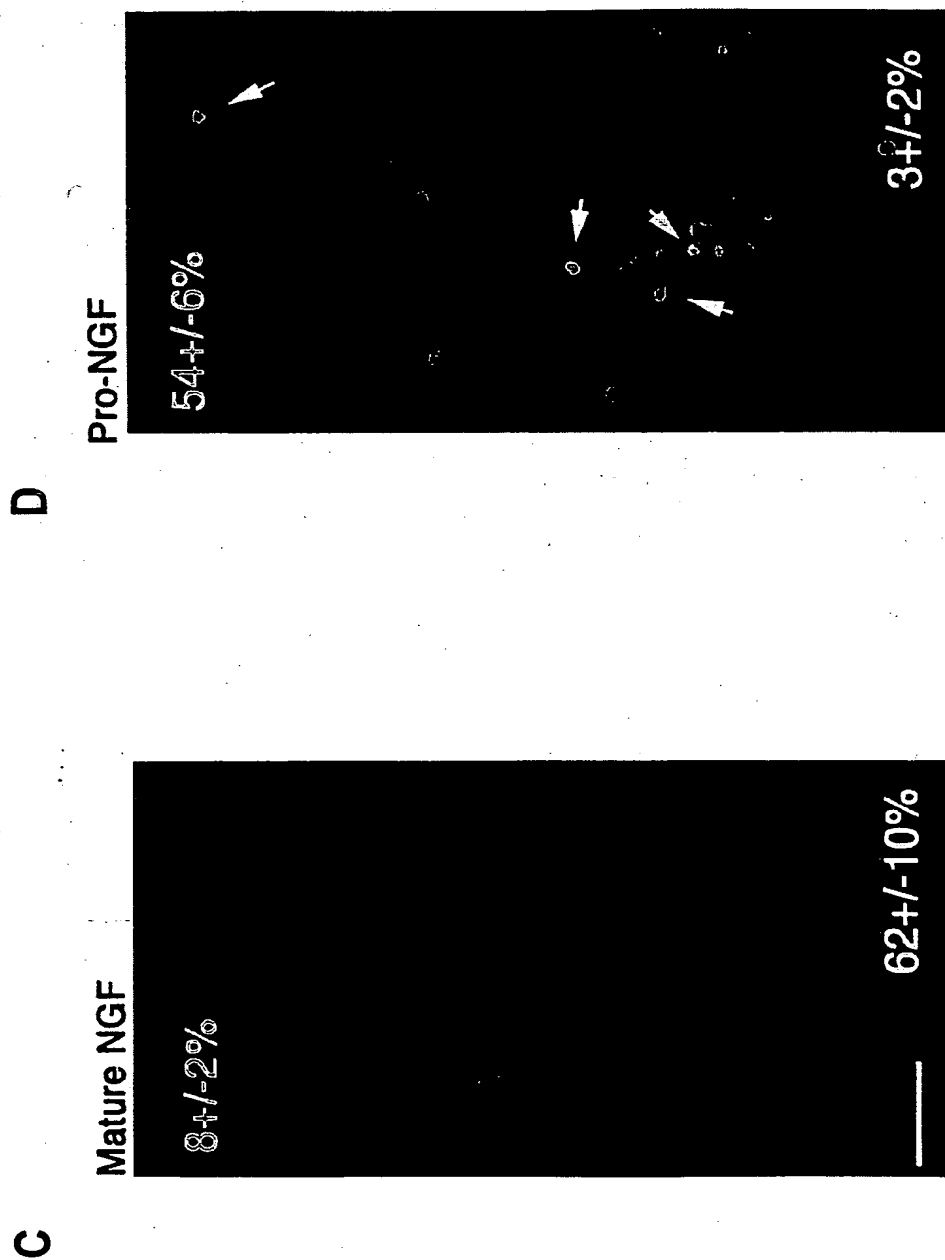


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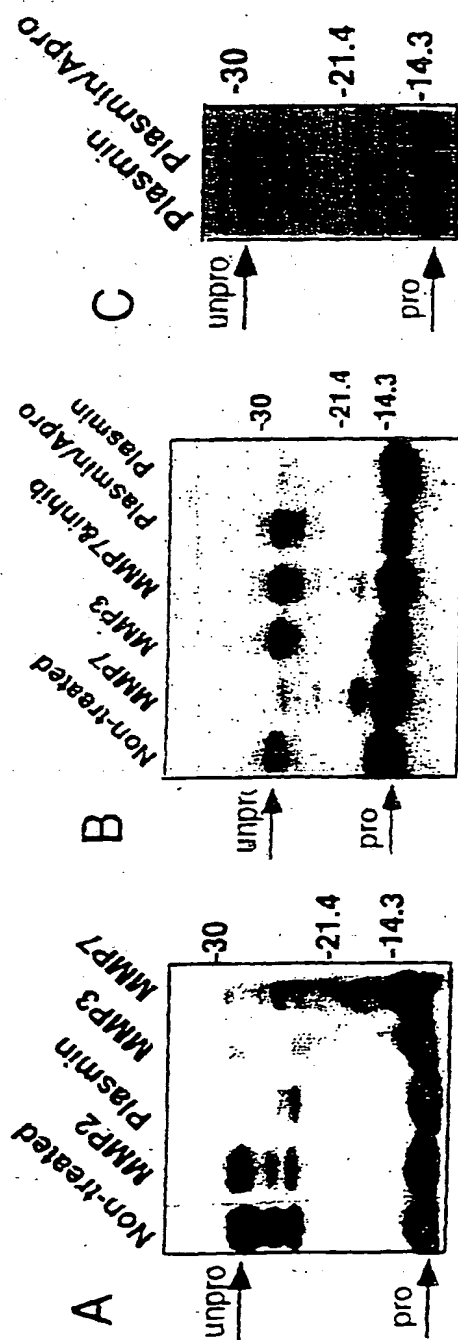


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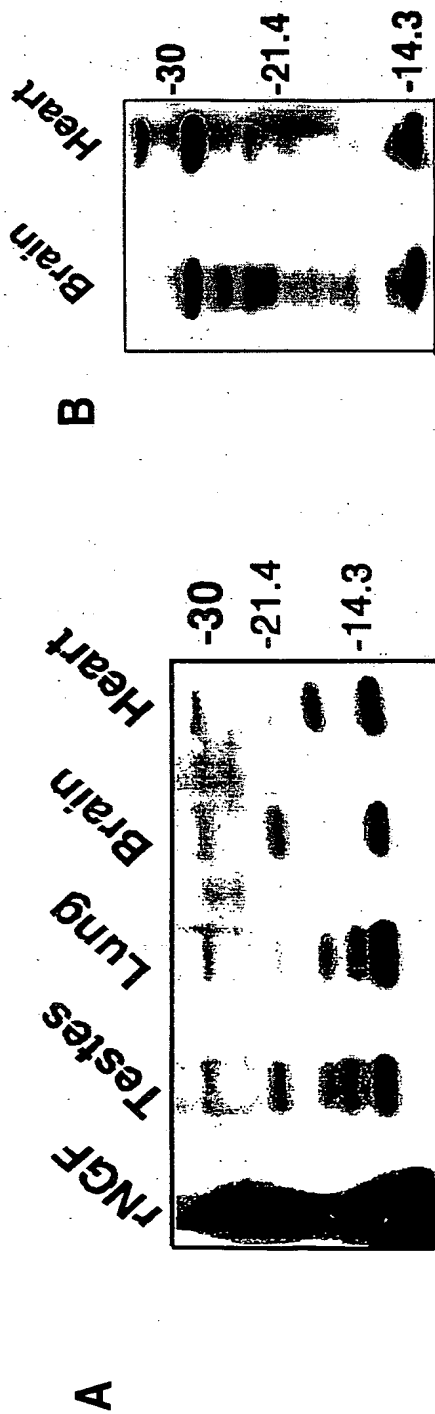


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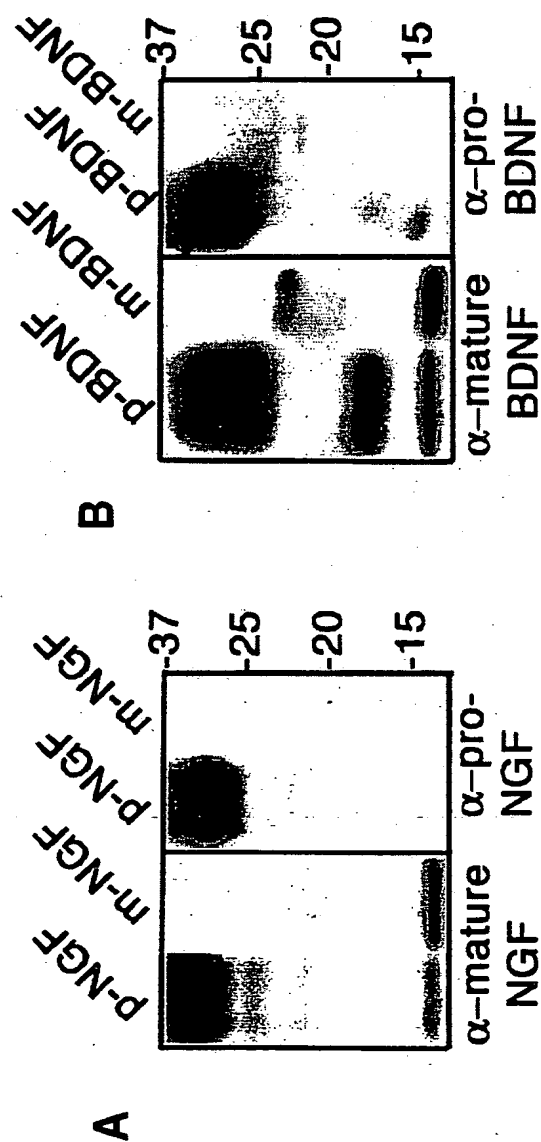


Figure 13



Figure 13

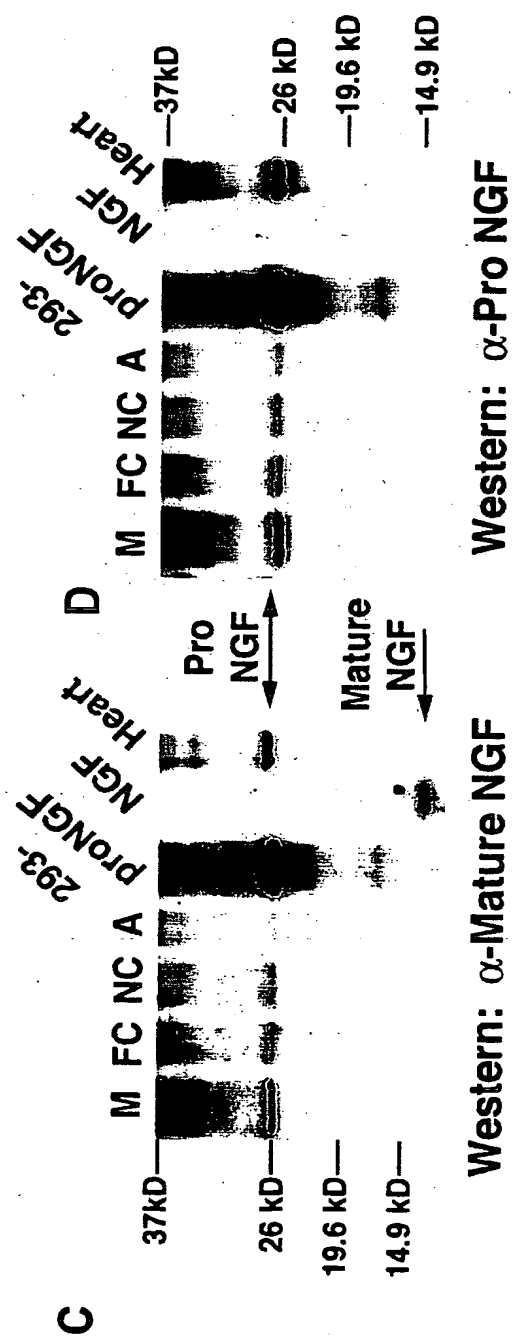
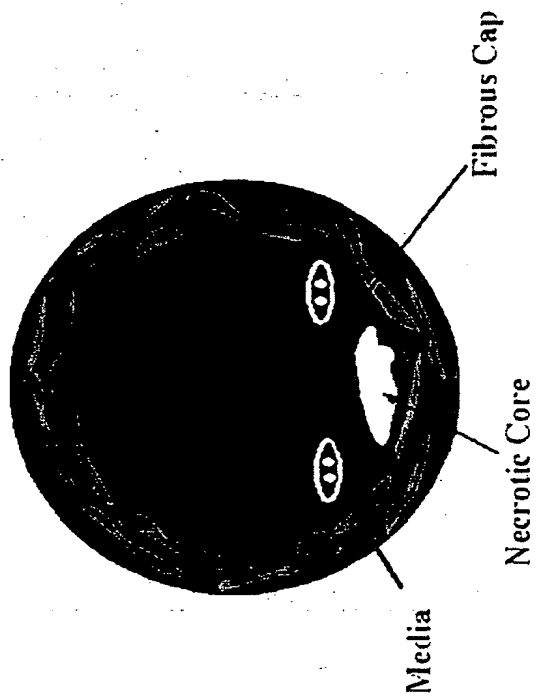


Figure 13E



Adapted from Breslow, J.L., Science, 272: 685